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FRANCESCO SIGNORE

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(Voir la suite à p. 3 de la couverture)

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Corso Vittorio Emanuele, 7 - Napoli - **Italie.**

NOTES, MEMOIRES ET RAPPORTS
DE VOLCANOLOGIE
PRÉSENTÉS À L'ASSEMBLÉE D'ÉDIMBOURG
SEPTEMBRE 1936

A. MICHEL-LÉVY

Détonation d'explosifs et volcanisme. Similitude de leurs effets.

(Avec 4 Planches)

Des recherches récentes [1]) que j'ai poursuivies en collaboration avec M. Henri Muraour, Ingénieur en Chef des Poudres, ont mis en évidence le rôle capital des ondes de choc dans les effets lumineux et certains effets mécaniques de la détonation des explosifs, et, à ce point de vue, leur prépondérance certaine sur les gaz émis par l'explosion.

La similitude de ces effets et de ceux constatés au moment de certaines explosions volcaniques m'a conduit à faire des rapprochements que j'exposerai ici brièvement.

I. — *Effets des ondes de choc provenant de la détonation des explosifs. Effets lumineux. Effets mécaniques.*

Les méthodes mises en oeuvre dans ces recherches et que nous avons désignées sous le terme de micropyrotechnie sont appuyées sur l'emploi de très petites quantités d'explosifs de grande brisance que l'on fait détoner dans l'obscurité devant l'objectif ouvert d'un appareil de microphotographie donnant des grossissements linéaires de deux à trois fois, ou bien devant un spectrographe.

Les explosifs utilisés sont des explosifs solides, tel

1) C. R. Ac. Sc., t. 198 p. 825, 1934 - id. p. 1499 - id. p. 1760 - id. p. 2091 - t. 200 p. 543, 1935 - id. p. 316 - t. 201 p. 828, 1935 - t. 202 p. 755, 1936 - id. p. 949 - t. 203 p. 316, 1936. Paris.
Chimie et Industrie. Vol. 32 - n.° 4 - Oct. 1934 - Paris.
Journ. de Physique. Série VII - T. VI - n.° 12 - p. 496 - 1936 - Paris.

que l'azoture de plomb, ou liquides, tel que le mélange à combustion complète de tétranitrométhane et de toluène.

Des granules à peu près sphériques d'azoture de plomb de 2 à 3 millimètres de diamètre sont posés à des intervalles de 5 à 6 millimètres sur une épaisse cale de verre suivant une courbe fermée en forme de collier ; l' explosif liquide ($0^{cc},4$ du mélange tétranitrométhane plus toluène à combustion complète) est placé dans une rainure circulaire de $2^{mm},5$ de largeur sur 3^{mm} de profondeur avec 30 millimètres de diamètre, pratiquée dans un bloc cylindrique de laiton, acier, ou plomb. L'amorçage est fait en un point du collier ou de la rainure circulaire par un fil métallique fin, chauffé électriquement.

Ces dispositifs ont pu être introduits dans de petites chambres à gaz, en verre ou en cellophane, ou dans des chambres à pression ou à vide.

Voici les résultats intéressants à signaler pour la comparaison avec le volcanisme ; ils sont relatifs aux effets lumineux et aux effets mécaniques destructifs.

1.° *Effets lumineux.*

On constate à l' instant précis de la détonation des phénomènes lumineux de grande intensité ; ces phénomènes sont dûs aux ondes de choc et principalement aux rencontres d' ondes de choc issues de l' explosif, animées à leur origine d' une vitesse considérable (6.000 à 8.000 mètres par seconde), et se propageant dans le milieu entourant avec une vitesse qui s'atténue rapidement ; ils ne résultent pas de l'expansion des gaz chauds émis par l'explosif qui leur est postérieure ; ni des particules de matières explosives incomplètement détonées qui ont pu être projetées dans l'atmosphère. Les deux photographies, Pl. I figures 1 et 2, sont suggestives à ce sujet. Sur la première (fig. 1) qui est celle de la détonation elle-même, on voit les granules d'azoture de plomb s' entourant d' une coque lumineuse et, en outre, une barre lumineuse dans l' intervalle des 2 granules à l' opposé du point d' amorçage ; cette barre lumineuse résulte de la rencontre des deux trains d'ondes de choc provenant des deux ondes de détonation

parties du point d'amorçage et cheminant en même temps sur les deux demi-cercles.

La deuxième photographie (fig. 2) est celle des dessins laissés par les dépôts de fines particules de plomb sur la plaque de verre après la détonation ; les gaz issus de l'explosif transportant ces particules se sont épanchés en tout sens autour de chaque granule ; à leur rencontre entre chaque groupe de 2 granules, il s'est formé une barre radiale de plomb déposé. Les luminosités de la figure 1 ne coïncident nullement avec les dessins de la figure 2 ; elles sont sans relation avec le mouvement et les rencontres des gaz de l'explosion. On voit clairement qu' elles sont bien dûes à l' action des ondes de choc sur l' atmosphère qui entoure les granules ou à leur rencontre entre elles-mêmes.

La forte aigrette lumineuse que l' on aperçoit sur la figure 1, Pl. III dans l' expérience faite avec l' explosif liquide (tétranitrométhane mélangé de toluène) résulte également de la rencontre des ondes de choc.

D' ailleurs, l' influence de la nature de l' atmosphère gazeuse entourante sur l' intensité de l' effet lumineux est venue confirmer cette théorie. La figure 1, Pl. II montre la grande brillance de la détonation dans l' argon ; la figure 2, Pl. II la très faible brillance de celle dans le butane.

La *chaleur spécifique moléculaire* des gaz entourant est donc un facteur important des luminosités. La température atteinte dans l'onde de choc et, par suite, sa luminosité, est d'autant plus élevée que la chaleur spécifique du gaz entourant est plus faible.

Un deuxième facteur s' ajoute à ce dernier ; en effet, à chaleur spécifique égale, la luminosité augmente avec la *densité du gaz*.

Par ordre de luminosité croissante, les gaz se classent ainsi :

diatomiques : Hydrogène, Azote, Oxygène, Chlore.

monoatomiques : Hélium, Néon, Argon, Krypton.

Si les luminosités étaient dues aux gaz de l'explosion, l' influence du milieu serait négligeable.

Deux particularités remarquables des luminosités d'ondes de choc doivent être retenues, leur *brièveté*, leur *intensité*.

La photographie de disques tournant à plus de dix mille tours a permis de préciser que la durée de l'effet lumineux était voisine de trois millionièmes de seconde. C'est une brièveté comparable à celle de l'éclair.

L'intensité lumineuse dans l'argon a pu être établie de façon approximative comme comprise entre 2.500.000 de bougies et 14.000.000 de bougies, pour une surface émettrice inférieure à 2 cm^2. Or, la valeur la plus faible, de 2.500.000 bougies, équivaut à 12 cm^2, 7 de la surface solaire. L'intensité de cette source lumineuse serait donc, dans l'argon, bien supérieure à celle du Soleil. Elle correspondrait à des températures supérieures à 10.000°.

Une autre observation doit être retenue, c'est, après le passage de l'onde de choc, une certaine persistance de la luminosité mais alors beaucoup plus faible, qui a pu être enregistrée sur un film fixé sur un tambour tournant dont la vitesse périphérique était de 90^m par seconde. La fraction du gaz activé par la rencontre des ondes de choc conserve, tout en se détendant, sa luminosité pendant un temps appréciable, de l'ordre de 2 à 3 dix millièmes de seconde.

L'étude du spectre de ces luminosités a apporté encore d'autres confirmations à la théorie émise.

Les spectres obtenus sont différents suivant les atmosphères gazeuses entourantes. En visant le point de plus grande brillance, les spectres sont à fond continu dans l'argon, le krypton, l'oxygène, l'acide carbonique ; mais à intensité à peu près égale dans le visible ils vont beaucoup plus loin dans l'ultra-violet dans les gaz monoatomiques à fortes densités (krypton-argon), que dans les gaz diatomiques (O^2) et triatomiques (CO^2). - figure 2, Pl. III, a. b. c.

L'extension dans l'ultra-violet est un indice de haute température ; la température dans l'onde de choc est bien, comme le veut la théorie, fonction de la chaleur spéci-

fique moléculaire du gaz traversé ; elle est bien plus élevée dans l'argon que dans l'acide carbonique.

Alors que l' introduction dans l' explosif liquide de différents métaux ne modifie en rien le spectre, par contre, la mise en suspension de ces mêmes métaux dans le gaz entourant a permis d' obtenir les spectres de ces métaux. Ces spectres sont apparentés aux spectres d'étincelle, non aux spectres de flamme ou d' arc ; ceci est un nouvel indice des hautes températures atteintes dans l'onde de choc (ex. spectre du fer fig. 2, Pl. III, d. e.).

2.° *Effets mécaniques.*

Les expériences poursuivies avec l'explosif liquide dans des blocs cylindriques de plomb à rainure circulaire ont permis de séparer deux effets mécaniques très différents l' un de l'autre.

a) Les ondes de choc qui, partant de la rainure dans laquelle est l'explosif, traversent le métal horizontalement et vers la base, déterminent au moment de leur passage dans l' air, sur les parois verticales du bloc, la formation de pelures métalliques arrachées par la brusque dépression qui suit l' onde de choc.

b) Les gaz émis par l' explosion soulèvent les rebords de la rainure qui prend la forme d' une large gorge très ouverte dans laquelle le métal est brillant et strictionné par la fusion, le déplacement rapide, et le refoulement réalisés par les gaz de l' explosion (fig. 1. 2. 3, Pl. IV).

II. *Volcanisme. Effets lumineux et effets destructifs à attribuer aux ondes de choc.*

On va voir que des luminosités et des effets de destruction dans certains phénomènes volcaniques paraissent bien résulter d' ondes de choc comme dans le cas des explosifs d'amorçage dont il vient d' être question ; les brisances sont comparables ou même plus fortes.

Un exemple des plus typiques d' un *phénomène lumimineux* de grande brillance résultant vraisemblablement d' ondes de choc issues d' une détonation volcanique, me paraît avoir été donné par l' éruption du 8 Mai 1902 de la Montagne Pelée ; une onde de choc se propageant en

tête de la nuée ardente détruisit St-Pierre de la Martinique. Dans l' ouvrage si riche en précieuses observations et en informations sévèrement contrôlées qu' A. Lacroix a publié sur ce volcan [1]), on trouve p. 243 un extrait du rapport du Capitaine Freemann qui se trouvait à bord du Roddam ; il s' exprime ainsi : « tout à coup retentit une « violente détonation qui ébranla la terre et la mer. Ce fut « une formidable explosion de la montagne qui parut s'en- « tr' ouvrir du sommet à la base pour donner passage à « une *flamme éclatante* (flashing flame) qui s' éleva dans « l' air, et à une poussée formidable de nuages noirs... *A « part cet éclair du premier moment, il n'y eut pas de feu ;* « ce fut simplement un nuage chargé de cendres et de ponces « portées à une température excessive qui en une minute ½ « franchit la distance qui sépare la volcan de la ville, dé- « truisant et brûlant tout sur son passage.

A la page 250, M. Lacroix écrit : « Il semble bien « établi par les observations faites dans la zone maritime « que la nuée ardente chargée de cendres a été précédée « par une *onde aérienne*, produite par la compression qu'elle « exerçait sur l' air ; cette onde est donc comparable à celle « qui précède les avalanches et aussi les projectiles lancés « par une bouche à feu.

Plus loin, page 257 : « Le second du Roraima a raconté « comment les mâts d' acier de son navire furent brisés net, « sans une bavure. On vient de voir que le premier choc « a été produit par l'onde de compression qui précédait la « nuée, de telle sorte que beaucoup de marins ont été pro- « jetés à la mer *avant d' être brûlés.*

Plus loin, page 271 : « Les navires ont tout d' abord « subi des actions mécaniques considérables qui les ont com- « plètement démâtés... ce sont les cendres très chaudes qui « ont mis le feu » page 272 : « la cendre est tombée tar- « divement... température probable de la nuée un peu su- « périeure à 450°...

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1) A. Lacroix. *La Montagne Pelée et ses éruptions.* Paris, 1904.

Ailleurs, M. Lacroix montre que la poussée destructrice était nettement dirigée ; les murs des maisons de St-Pierre en direction E. O., parallèles au front d'onde, ont été abattus ; les murs N. S., perpendiculaires à l' onde étant restés debout.

De ces considérations relatives à la nuée ardente de la Montagne Pelée du 8 Mai 1902, il ressort quelques faits qui paraissent bien établis.

Une luminosité de grande brillance, donc de très haute température, peut-être de l'ordre de 10.000°, s'est produite sur le volcan, au contact de l'atmosphère, au moment de l' explosion ; gaz et cendres ne sont venus qu' à la suite, formant des nuages noirs, sans luminosité. Cette succession rappelle celle des brèves et intenses luminosités de la détonation de l'azoture de plomb et du tétranitrométhane au contact de l'atmosphère, suivies d'épanchements gazeux obscurs. Dans le premier comme dans le deuxième cas, il s'agit vraisemblablement de luminosités provoquées par le départ d'ondes de choc dans l'atmosphère entourante, par compression brutale, élévation de température et ionisation.

Une confirmation de cette hypothèse se trouve dans les effets destuctifs constatés à distance, à bord des navires, comme tout premier événement précédant l'arrivée des cendres chaudes et des gaz et dans la destruction des murs de St-Pierre perpendiculaires à la direction de propagation de l'onde. Si l' on se reporte à ce qui a été dit plus haut sur la formation des pelures de plomb arrachées par la brusque dépression qui suit immédiatement l'onde de choc dans son passage du bloc de plomb dans l'air entourant, lors de la détonation du mélange tétranitrométhane plus toluène à combustion complète, on ne peut qu' être frappé de l'analogie de ces phénomènes destructifs dirigés ; la démolition des maisons de St-Pierre comme M. Lacroix l' a bien montré, n' a pas été due à un bombardement par projections de roches pyroclastiques et de gaz de l'explosion, mais au passage d' une brusque compression, suivie d' une profonde dépression, celle de l' onde de choc qui, à son point de départ, a dû produire la luminosité initiale.

Il semble que les brisances dans l'explosion volcanique péléenne soient au moins aussi fortes que dans la détonation des explosifs d'amorçage, sinon très supérieures.

Il faut rappeler ici un autre phénomène volcanique dû à des explosions sous-marines ; la projection de l' eau de mer en forme de gerbe bordée de dents de scie, que l' on a pu photographier sur les côtes des îles de la Sonde. Or, une charge de dynamite détonant à 15 mètres sous l' eau, produit une gerbe d' eau dont la forme est tout à fait comparable à la précédente.

D' autres exemples en faveur de l' hypothèse des luminosités dues aux ondes de choc peuvent être cités. Dans le même ouvrage de M. A. Lacroix (page 320) il est indiqué qu' « Anderson et Flett, à bord d' un bateau par le « travers du Carbet, virent lors de l' éruption du 9 Juil- « let 1902 de la Montagne Pelée, après 8 h. 20 du soir, des « *phénomènes lumineux intenses* au cratère ; puis il en partit « des projections de blocs incandescents. Aussitôt après, le « haut de la montagne s' éclaira d' une *lueur intense*.... « L' incandescence ne dura qu' une minute ou deux ; elle « fut suivie d' une nouvelle nuée ardente... qui, éclairée par « la lune, était noire et parcourue par des éclairs.

M. Romer signale dans un important rapport sur l' éruption de la Montagne Pelée de 1929 l'apparition de lueurs étincelantes dans les grandes nuées des 6, 16, 21 Décembre [1]).

Le Professeur Francesco Signore dans une étude sur l' « Allure des facteurs météorologiques à l'Observatoire Vésuvien pendant l'éruption terminale du 3 au 8 Juin 1929 » [2]), rappelle que le Professeur Malladra a constaté au Vésuve le 5 Juin à 10 h. du matin une explosion sèche très forte, accompagnée par un éclair très vif, qui fut parfaitement visible quoique le soleil brillât dans le ciel.

1) Romer — *La dernière éruption de la Montagne Pelée*. Bull. volcan. 8e année 27-30, Naples 1936.

2) Signore F. — *Allure des facteurs météorologiques à l'Observatoire Vésuvien, éruption du 3 au 8 Juin 1929*. Bull. volcan. 7e année 23-26 Naples 1933.

Comme conséquence des analogies ainsi établies, est-il possible de mettre en discussion les causes mêmes de certaines explosions volcaniques ?

Il est généralement admis que les explosions volcaniques sont dues à une mise en tension des gaz et vapeurs existant dans les magmas, suivie d'une brusque détente par rupture des carapaces refroidies. Est-ce là la seule cause de ces explosions ?

N' est-il-pas raisonnable d' imaginer la genèse possible, au sein des magmas, de combinaisons chimiques devenant explosives dans certaines conditions de température et de pression ?

L' existence dans les fumerolles des volcans, de carbures d' hydrogène, d'azote, la présence, dans les magmas, de métaux, rendent l' hypothèse vraisemblable. La brusque désintégration de matières explosives expliquerait mieux les effets de grande brisance qui accompagnent certaines explosions volcaniques. La détonation en profondeur de ces matières pourrait être invoquée comme cause de tremblements de terre et origine d'ondes séismiques.

Quoiqu' il en soit, il paraît possible et souhaitable d' apporter par l' observation spectrographique des luminosités brèves et intenses du début de certaines explosions volcaniques, la confirmation de cette hypothèse, et la preuve qu' elles résulteraient de la grande élévation de température de l'atmosphère au départ de l' onde de choc, et non des flammes ou des gaz chauds de l' explosion.

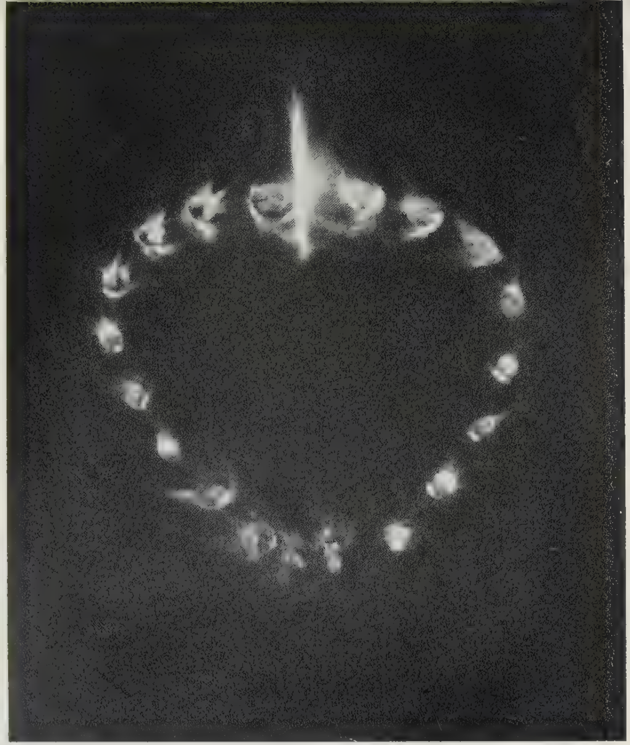

Fig. 1.

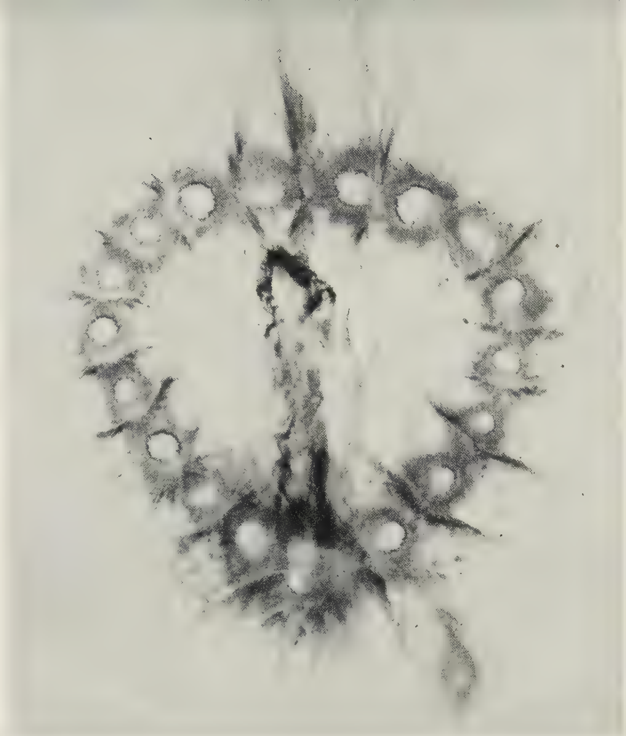

Fig. 2.

Fig. 1. — Phénomènes lumineux de la détonation dans l'air de granules d'azoture de plomb disposés en collier, amorçage du granule de base par un fil métallique chauffé électriquement. Une barre lumineuse à l'opposé, à la recontre des ondes de choc.

Fig. 2. — Photographie des dépôts de plomb laissés par les gaz de l'explosion après la détonation ; des barres de plomb entre chaque groupe de deux granules.

MICHEL-LÉVY — *Détonation d'explosifs et volcanisme. Similitude de leurs effets.*

Fig. 1.

Fig. 2.

Phénomènes lumimeux de la détonation de granules d'azoture de plomb en collier.

Fig. 1. — dans l' argon

Fig. 2. — dans le butane.

Fig. 1.

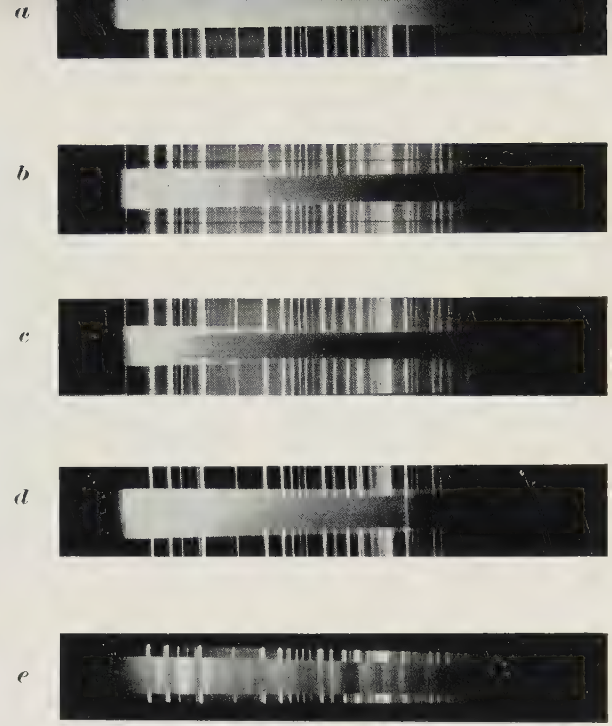

Fig. 2.

Fig. 1. — Phénomènes lumineux de la détonation de $0^{cc},4$ d'un mélange de tétranitrométhane et de toluène à combustion complète (explosif liquide) dans la rainure circulaire d'un cylindre de laiton.

Fig. 2. — Spectres des luminosités du dispositif précédent 1° en visant le maximum d'intensité lumineuse à 20^{mm} au-dessus du liquide
a) dans l'argon, 1 seule détonation, spectre continu allant très loin dans l'ultra-violet ;
b) dans l'oxygène, 5 détonations, spectre continu allant moins loin dans l'ultra-violet ;
c) dans l'acide carbonique, 8 détonations, spectre continu court.
2° d) dans l'argon, mais en visant dans une région moins lumineuse à 60^{mm} au-dessus du liquide, avec du picrate de fer dans le mélange explosif, 1 seule détonation, spectre continu, pas de raies du fer.
e) à 60^{mm} au-dessus du liquide, mais en ayant répandu, avant la détonation, des fumées d'hexogène et de picrate de fer dans l'argon, 1 seule détonation, spectre de raies du fer. Le spectre de référence est celui de l'arc au mercure.

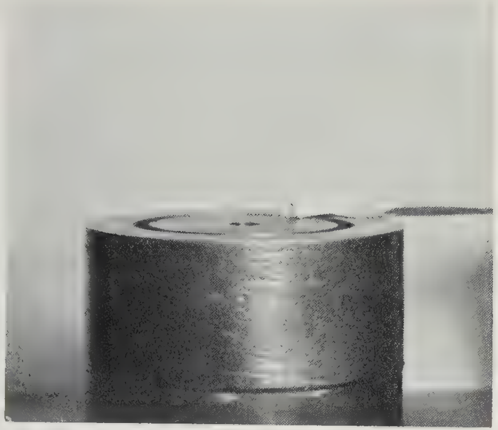

Fig. 1.

Fig. 2.

Fig. 3.

Fig. 1. — Cylindre de plomb, avant détonation, avec rainure pour l'explosif liquide (mélange à combustion complète de tétranitrométhane et de toluène).

Fig. 2. — Le même cylindre après la détonation montrant les deux pelures de plomb arrachées sur les parois verticales par le passage de **l'onde de choc** ; la première très rabattue, entrainée par un premier train d'ondes, la seconde, peu rabattue, entrainée par un deuxième train d'ondes réfléchies.

Fig. 3. — Le cylindre après détonation vu en-dessus pour montrer la large cuvette ouverte autour de la rainure primitive par les **gaz de l'explosion** avec fusion et striction du plomb.

J. E. RICHEY
H. M. GEOLOGICAL SURVEY, SCOTLAND

Some Features of Tertiary Volcanicity in Scotland and Ireland

(with 10 text-figures and 2 plates)

The problems which confront the volcanic geologist in Britain are especially well illustrated in the volcanic and intrusive assemblages of the Tertiary igneous period. The rocks occur over a large part of our islands, but they are concentrated chiefly along the western seaboard of Scotland and in the north of Ireland (fig. 1). They form one of the remnants of the vast Thulean province, which is represented farther north in the Faeröe Islands, and Iceland, and on the north-west side of the North Atlantic in Greenland. Only in Iceland has volcanic activity continued on to modern times. Elsewhere the volcanoes and their many and diverse products have been eroded deeply or have sunk beneath the waters of the ocean.

The level to which denudation has reduced the Thulean volcanoes in this country permits us still to observe the earlier of the lava-flows and also to examine the interior of the volcanoes during later stages The present surface, in fact, gives us a comprehensive view of volcanic phenomena, since it provides cross-sections at various levels between the tops of the volcanic mountains of bygone days and the reservoirs of molten rock from which the volcanoes were fed.

Two main problems present themselves for consideration. First, what was the mode of origin of the early lavas ? Or these, sufficient outcrops are left for us to envisage a thick and extensive basaltic lava - plateau. Secondly, what is the significance for the volcanologist of the pro-

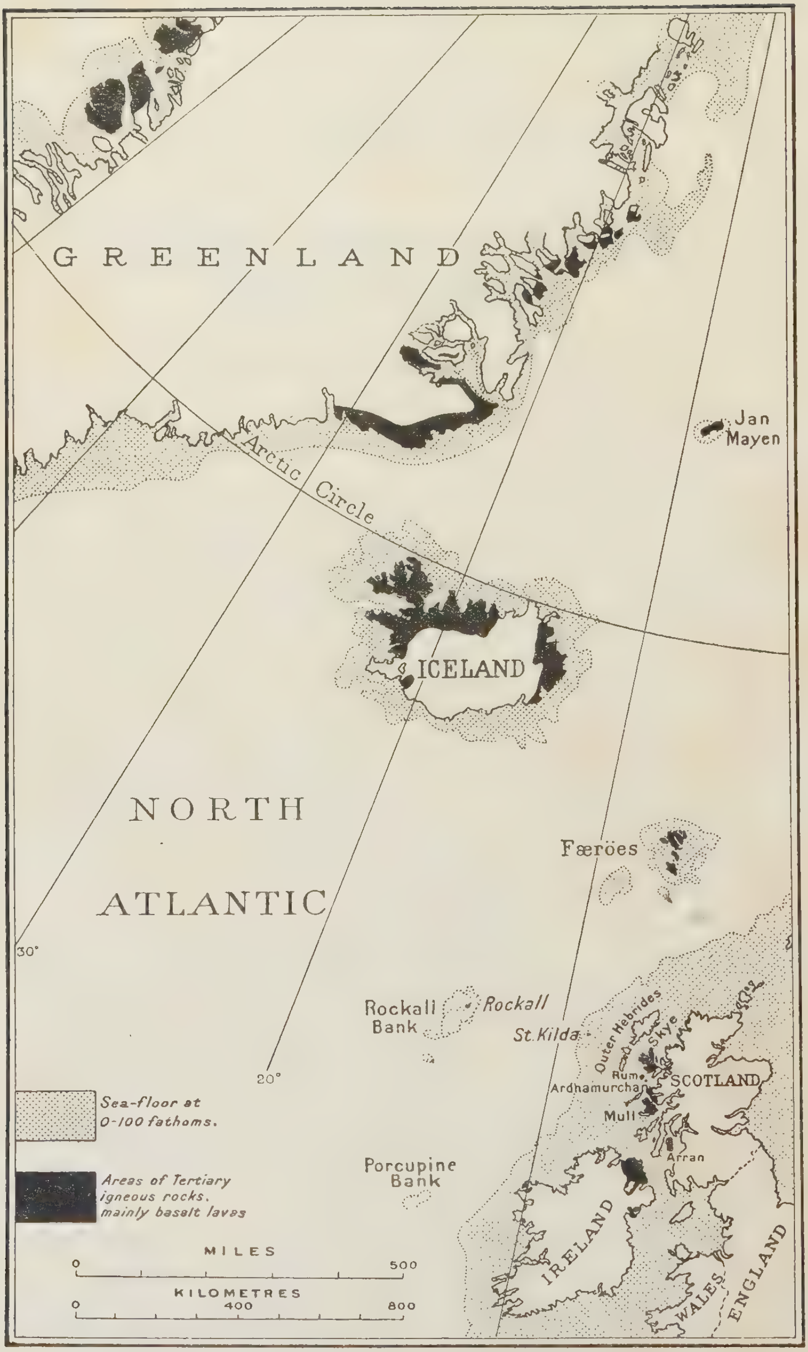

Fig. 1.—Map of the North Atlantic (or Thulean) Tertiary Igneous Province.

(Rep., with permission, from Fig. 17, Tertiary Volcanic Districts, Scotland, Mem. Geol. Surv. Scotl., 1935).

longed and essentially intrusive period which succeeded the eruption of the basalts ?

The Problem of Fissure Eruption versus Eruption from Central Vents

The basaltic lavas are widely distributed. They stretch from the north of Skye to the north of Ireland. In contrast, the later intrusive rocks are grouped for the most part around a few points along the lava - belt. These points are termed intrusion - centres. In addition, however, a certain class of intrusion, the north - west basaltic dykes, have, like the lavas, a regional distribution, and indeed extend far beyond the present restricted limits of the lava-plateau to traverse the pre - Tertiary rocks. Some geologists have argued that the feeders of the basaltic flows are represented by the dykes. This theory of fissure - eruptions was strongly advocated by Sir Archibald Geikie many years ago, and it receives support from the fact that fissure - eruptions are a feature of the modern Icelandic Thulean plateau. In our islands, however, no instance of a dyke directly connected with a lava is known. On the other hand, there are many small scattered vents and plugs that pierce the basaltic plateau. Further, more recent work in Britain has brought to light remarkable evidence in regard to the distribution and age relations of the dykes, and to the existence of an extensive basaltic caldera at one of the intrusion - centres (Mull).

The dykes are now known to have a geographical arrangement. They run in north - westerly extending groups, or linear swarms. Each swarm passes through one of the intrusion - centres, in the vicinity of which the number of individual dykes attains a maximum. Around the centres, too, multiple dykes are congregated. A relationship between the centres and the dykes is evident, and an explanation which we owe to Dr. E. B. Bailey is not difficult to understand.

The dykes represent tension - cracks infilled with magma, as has long been realised. The crustal tension found

relief by fracturing across the weaker places, namely, the intrusion-centres, where the crust was pierced by large and slowly consolidating intrusions or, at a deeper level, by local reservoirs of magma. The crust under tangential tension would break across at these weak places, just as a tear will occur most readily across a perforation in a sheet of paper.

This explanation of the dyke-swarms leads to the conclusion that the centres were in existence *before* the formation of the swarms. Our next step is to consider the age relations of these important centres to the lavas themselves. We are fortunate that we can do so. In the Island of Mull, within the very area where later intrusion was most rife, such evidence is still preserved, and will presently be described. With this exception all the central intrusive districts are now occupied almost entirely by post-lava rocks — extensive and multitudinous intrusions and explosion-vents. No certain trace of a connection with the lava-period remains.

Characteristics of the Basaltic Plateau

Let us consider first some of the characteristics of the basaltic plateau. Any view of the lava-country shows its denuded character, with the lava-flows outcropping as flatly-extending sheets along the hill-sides. Clean-cut rock-sections along coastal cliffs display the structure of individual flows, each of which consists of a solid jointed lower portion and an upper layer of slag. Upon the slag there frequently rests a bed of red clay, which marks a period of quiescence during which the lava-top was weathered. The clays afford a demonstration of the fact that the lavas were erupted sub-aerially, and this conclusion, it is fitting to recall, was first arrived at by a distinguished Frenchman, Ami Boué, in the early part of last century.

Sedimentary beds are also found occasionally between the lava-flows, and on the evidence of the abundant remains of plants which they contain (chiefly leaves of trees),

the age of the eruptions has been fixed as early Tertiary. Seams of lignite are also encountered, and pollen grains from these, which have been recently extracted and determined by Dr. J. B. Simpson, disclose the occurrence of a varied assemblage of trees with resemblances to the modern East Asiatic flora. The sediments are, in fact, signs of the presence of lakes amidst the lava - fields, around which forests flourished for a time. An actual tree - trunk, 50 feet in height, is preserved at one place in the west of Mull, where it was discovered by MacCulloch many years ago, enveloped in a lava - flow.

The Basaltic Caldera of Mull

Around the Mull centre of intrusion the greatest development of lavas known in the British area is encountered, being 5,000 to 6,000 feet in thickness (fig. 2). Elsewhere the conditions for their preservation from erosion were less effective. Generally, the lava-sheets are flat-lying or are gently inclined. But around the Mull centre they have been folded into deep synclines. So we find there later portions of the ancient volcanic plateau than elsewhere. The folding is localized around Mull, and is attributed by Bailey to the outward pressure of certain early intrusions belonging to that centre.

The map of Mull (fig. 2) shows that the lavas consist of two successive groups, a lower group, mainly of olivine-rich basalts, and an upper, mainly of olivine - poor basalts. In addition, within the interior of the area of intensive intrusion, lavas occur which are of similar composition to those characteristic of the upper group and which are also of great thickness collectively. From their structure it is concluded that these centrally - situated flows travelled into water, and not over a terrestrial surface like the surrounding basalts. Their structure is that of pillow lavas, such as have been observed in process of formation at the present day where lava enters the sea. It is supposed that lakes were formed again and again in the interior of a

Mull volcano. But, unlike the sediment - filled lakes of the surrounding plateau, practically no sediment is found with the pillow - lava assemblage. The presence of crater - lakes, with an interior drainage bearing little sediment, is the conclusion which BAILEY has drawn from all these facts.

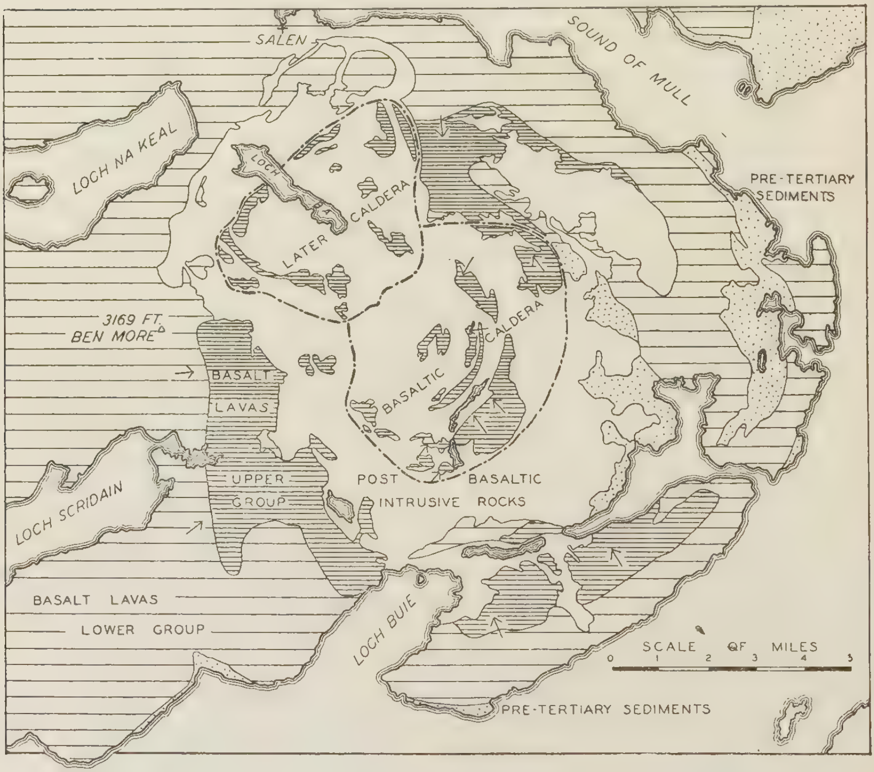

Fig. 2. — Sketch Map showing the outcrops of the Tertiary Basaltic Lavas and the two Calderas of Central Mull, Scotland. (Re-drawn, with permission, from Pl. III, Tertiary and Post-Tertiary Geology of Mull, etc., Mem. Geol. Surv. Scotl., 1924).

Thus we picture a wide crater or caldera in the interior of Mull during the basaltic period. The caldera was renewed again and again by subsidence of its floor as it filled with lava. The lava is supposed to have flowed inwards from the caldera rim and also to have spread outwards to build a great shield - volcano (fig. 3). At one place where

Fig. 3. — Reconstruction of the Basaltic Volcano of Central Mull, Scotland, in bird's eye view and in section.
(Rep., with permission, from Fig. 19, Tertiary Volcanic Districts, Scotland, Mem. Geol. Surv. Scotl., 1935)

the rim of the caldera may once have been, there is evidence of a fault with a downthrow towards the interior of many thousands of feet. Elsewhere the actual caldera-margin has been obliterated by later intrusion and volcanic explosion. But as a consequence of the subsequent explosion suggestive evidence is forthcoming in support of the conclusion that the interior of Mull has indeed sunk.

The Later History of the Basaltic Caldera of Mull

The explosions were due to the uprise of acid magma, and belong to the essentially intrusive period that succeeded the basaltic eruptions (fig. 4). Their products, volcanic agglomerates, which mainly occupy necks and vents, include not only fragments of acid volcanic rocks but also pieces of the older rocks through which the explosions broke. Now, in the interior of Mull, within the area of the basaltic caldera, and also within a later caldera to the north-west, all the pre-vent rocks found in the agglomerates are Tertiary types, either intrusions or basalt lavas. Fragments derived from the underlying pre-Tertiary sediments have not been noted. In contrast, outside the area of the caldera, pieces of the pre-Tertiary rocks are frequent and often abundant. The conclusion is drawn that within the interior of Mull the pre-Tertiary sedimentary «floor» upon which the basaltic plateau rests had sunk so far down that it was unaffected by the volcanic explosions. The subsidence must have been considerable. We know that the Tertiary explosion-volcanoes were capable of transporting material broken off from their walls upwards from a great depth. An especially remarkable example from Mull itself is a large boulder of schist, 200 yards in length, which lies in a vent-agglomerate almost 2,000 feet above the highest point from which it could have come.

The arrangement, too, of the plutonic intrusions which are associated with the explosion-vents points to the existence of a caldera. These intrusions partly ring around the area where the pillow-lavas are found, as though si-

tuated along the ancient ring - fissure that bounded the caldera. This may well be the case. Similar ring or arcuate - shaped intrusions of steep form, or ring - dykes, are known to occur in Mull and elsewhere along curved planes of fracture or ring - faults, and either individually or collec-

Fig. 4. - Sketch Map showing outcrops of volcanic agglomerates mainly in vents in Central Mull, Scotland, and their distribution in relation to the Calderas.

(Re-drawn, with permission, from Fig. 29, Tertiary and Post-Tertiary Geology of Mull, etc. Mem. Geol. Surv. Scotl., 1924).

tively to enclose a central subsided « core ». An idealised representation is given in fig. 6.

The state of affairs after the first intrusion of acid magma along the margin of the basaltic caldera is shown

in sectional view in fig. 5. The intrusive acid masses are those which are believed to be responsible for the folding around the interior of Mull, to which we owe the preservation of the upper group of the plateau lavas. They are broken through and much brecciated by the earliest of the explosion - vents. The volcanic cones have been completely weathered away, except for certain supposed basal remnants which are preserved in the concentric synclines

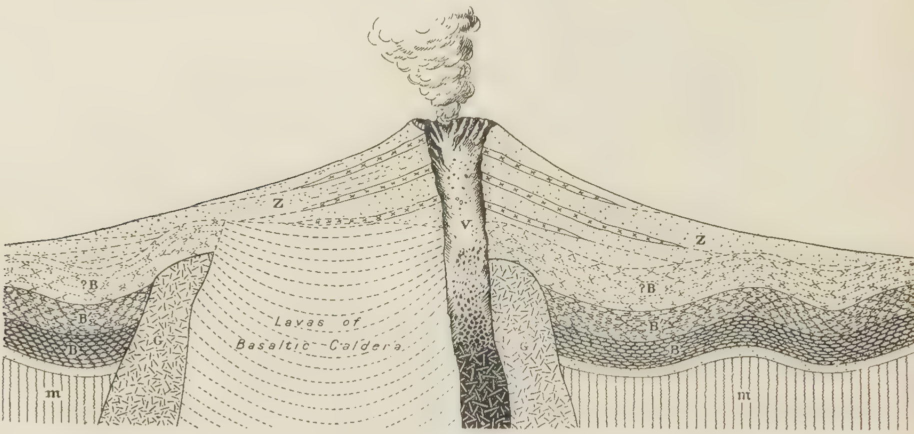

Fig. 5. — Reconstruction of the Mull Volcano, in section, during the early acid explosive phase.

(Rep., with permission, from Fig, 26, Tertiary Volcanic Districts, Scotland, Mem. Geol. Surv. Scotl., 1935).

m, Moine Schists overlain by Mesozoic strata ; B, B', ? B, Tertiary lavas of the Mull basaltic volcano ; B, lower group ; B', upper group ; ? B, supposed lavas later than B' (removed by denudation); G, granophyre intrusive around the basaltic caldera, giving rise to the peripheral folding ; V, early explosion-vent. due to an acid (rhyolitic) magma ; Z, supposed ashes and lavas of cone-volcano (removed by denudation).

(p. 7) ; but the reconstruction given in the Figure may serve as a picture of one of the volcanoes of this period.

Another type of intrusion is also related spatially to the basaltic caldera. The intrusions concerned consist of thin centrally - inclined sheets. They collectively form a belt which almost completely surrounds the basaltic caldera, and they are everywhere inclined inwards and downwards at about 45° towards a point beneath the centre of the caldera. These intrusions have been termed by Bailey

« cone - sheets ». Individual sheets only extend around part of the belt, but the shape of the belt as a whole resembles that of an inverted cone.

The apex of the cone lies far beneath the present surface. It may be calculated from the observed inclinations of the cone-sheets at what depth this point will be reached. It works out at about 5 kilometres. According to a theory of the mode of formation of cone - sheets which Dr. E. M. ANDERSON has formulated, this point coincides

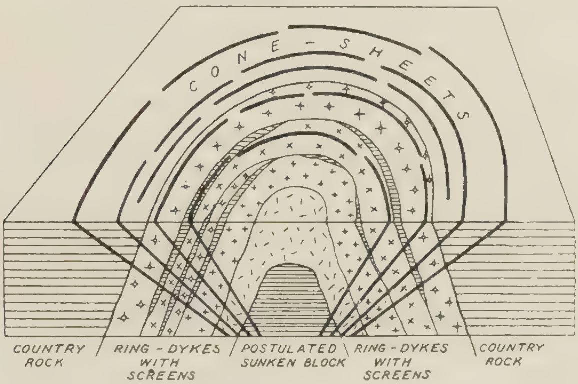

Fig. 6. — Ideal Ring Complex of Ring-dykes and Cone-sheets, in plan and section.

(Rep. with permission, from Fig. 2, Tertiary Ring Structures in Britain, Trans. Geol. Soc. Glasgow, vol. XIX. pt. i, 1932).

with the top of a magma - reservoir ; and Dr. ANDERSON has assigned the fractures responsible for the ring - dykes as well as the cone - sheets to stresses set up in the roof of the reservoir by the varying pressure of the magma.

We have now advanced far enough to be able to give a connected summary of the history of an igneous centre such as that of Mull. First, a reservoir filled with basaltic magma and of restricted extent laterally came into existence at a comparatively high level in the crust. This fundamental deduction serves to explain all later events. A ring - fracture extended from the top of the reservoir to the surface, and a caldera of subsidence was initiated. With the uprise of basalt magma along the ring fissure to

the surface, the lava period began. Eruption occurred either directly from the caldera's rim or, perhaps in part, from fissures which may have radiated from its outer side. The swarm of fissures at Kilauea is a parallel type. Next, a change in the composition of the magma to intermediate and acid types took place in the upper part of the reservoir. Continued subsidence of the caldera led to the intrusion of acid magma along the caldera - margin under a pressure sufficient to drive outwards the basaltic plateau into a series of concentric folds. Then came further changes in the composition of the magma, acid and basic types alternating with one another, with the formation of both ring - dykes and cone - sheets. Explosion - vents associated with an uprise of acid and intermediate magma broke through at two or more different periods. Finally, when ring - dykes had been developed almost to the centre of the area within the basaltic caldera, activity ceased.

The Later Caldera of Mull

The history of the Mull volcano did not end there. Active intrusion was continued around another centre which was situated a few miles to the north - west of the basaltic caldera (*see* fig. 2). The position of the magma - reservoir, it is supposed, had merely been shifted laterally. Around the later centre we find both cone - sheets and ring - dykes, the latter being associated with subsidence of the rocks enclosed within them. The phenomena characteristic of the first centre were repeated in the second, except that at the level of erosion which we observe lavas are not found and there is little certain indication of explosive action. We are in this case far beneath the level of surface volcanicity.

The Final Phases of Activity in Mull

North-west basic dykes in great profusion cut through all the intrusions indiscriminately including the latest of those which are related to the second centre. They are

thus separated in time from the plateau lavas by all the complexity of centrally related intrusions which we find in Mull. A proportion of the dykes are earlier than certain of the central intrusions. But the greater number form the last intrusive episode in the igneous history of the area.

This brings us to the last page of the story, the waning of the volcano and the release of vapour only. Within an area 15 miles in diameter the rocks of Mull are altered by pneumatolysis. All the dykes from the interior are altered by hot vapours, though not to such an extent as the rocks which they cut. The alteration no doubt went on during the entire igneous period. But much of it must have taken place at its close.

The Post-Basaltic Volcanoes of Ardnamurchan and Slieve Gullion

Ring intrusions and the shift of centre which they show are a common-place feature of our Tertiary volcanoes. For example, in Ardnamurchan explosion-vents, ring-dykes and cone-sheets are well developed, and in this case they indicate a shift of the centre on two occasions (Fig. 7). Further, the stages in the growth of a volcanic mountain seem to be indicated by the fact that around the earliest centre explosion-vents are prevalent, and do not occur in relation to the latest centre. Around the second centre, explosive brecciation of ring-dykes, and the occurrence of only one small vent, point to an intermediate level beneath a volcanic cover. The marked up-doming of the sedimentary country rocks around this centre also suggests relatively high-level conditions. We appear to be observing in this district cross-sections of volcanoes cut at three different levels relatively to the land-surface existing when each was active.

As indicated above, there is evidence of a causal connection between the arcuate or ring-shaped intrusive masses of Mull and Ardnamurchan and surface volcanicity. The

most striking case, however, comes from Slieve Gullion in the north of Ireland. A partial geological map of this Tertiary centre is given in Fig. 9. It shows agglomerate-filled vents arranged along a ring-fissure, which is more

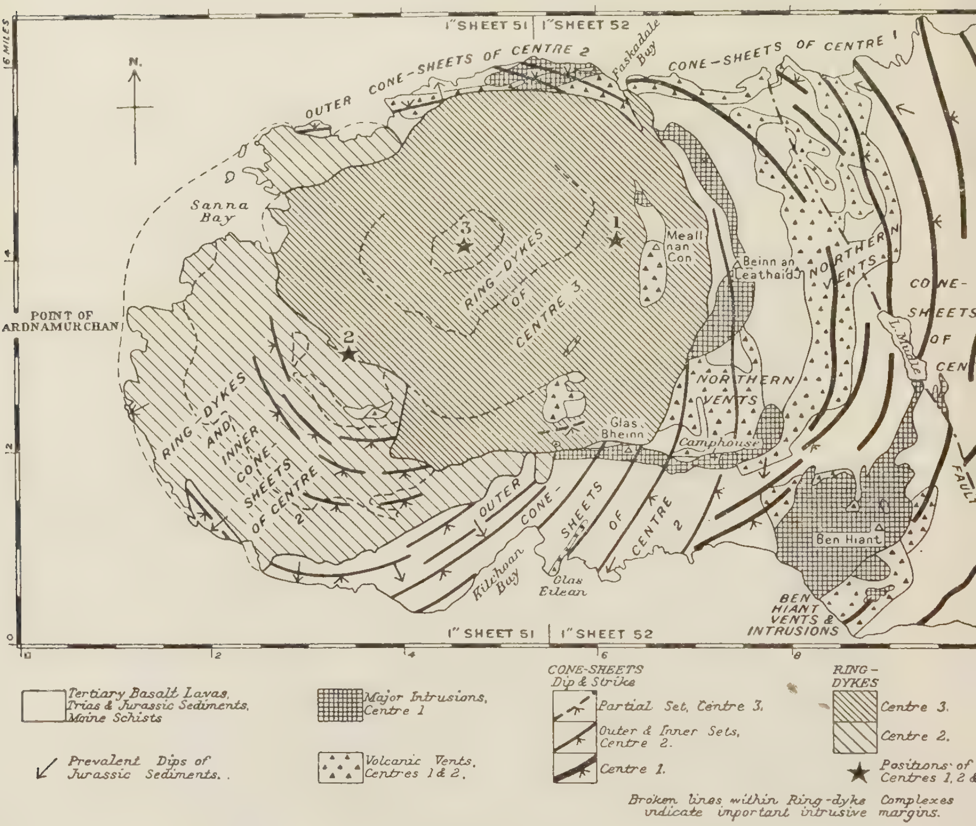

Fig. 7. — Sketch Map of the three Ring Complexes of Ardnamurchan, Scotland.

(Rep., with permission, from Pl. II, The Geology of Ardnamurchan, etc. Mem. Geol. Surv. Scotl., 1930).

precisely marked by two ring-dykes. The ring-dykes are later than the vents in their neighbourhood. Originally there was practically no gap in the Slieve Gullion « circle of fire », or at any rate in its feeders. Now tke ring is in-

Fig. 8. – Panorama showing the topography of the ring-dyke complex around Centre 3, Ardnamurchan, Scotland.

The ring-shaped ridges and hollows are due to the differential erosion of the ring-dykes. The central rock-knob marks the outcrop of a central boss of quartz-monzonite. The outermost ring-ridge, 3 miles in diameter, is formed of a ring-dyke of eucrite.

(Rep., with permission, from Pl. VI, The Geology of Ardnamurchan, etc., Mem. Geol. Surv. Scotl. 1930).

complete, mainly owing to later Tertiary intrusions along its south-east side.

The vents and felsite intrusions along the south-west side of the ring were formed first. The ring was then completed with the opening of a few later vents along it and the intrusion of a ring-dyke of granophyre.

The fragments in the agglomerates were derived almost entirely from adjacent rocks which form the walls of

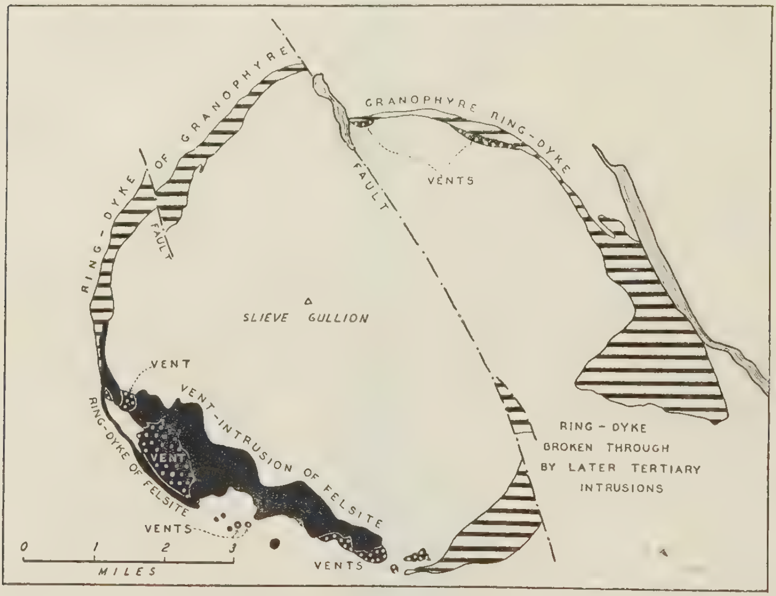

Fig. 9. — Sketch Map showing the volcanic-intrusive Ring around Slieve Gullion, North Ireland.
(Re-drawn, with permission, from Pl. XV, The Tertiary Ring Complex of Slieve Gullion, Quart. Jour. Geol. Soc. Lond. vol. LXXXVIII, 1932).

the vents. There are no true bombs. Their formation heralded the major irruption of the magmas which gave rise to the ring-dyke intrusions. Large landslipped masses of plateau basalt lavas occur in the earlier vents. They show: 1. that the vents are later than the basaltic period; 2. that the vents pierced the basaltic plateau; 3. that the succeeding intrusive magmas were thus within, what one

might describe as, "striking distance" of the surface, and in all probability fed eruptions.

Calderas Essentially Due to Explosion

The diversity of the views which are held by volcanologists concerning the formation of calderas is well known [1]). The geologist, who deals with deeply situated cross-sections of volcanoes, would seek to distinguish two main classes, namely, the caldera essentially due to subsidence of deep-seated origin and the caldera essentially due to subsidence brought about by explosion. The basaltic caldera of Mull is considered to be an example of the first class. The great explosion-vents of later date than the basaltic plateau, which occur at almost every one of the British Tertiary intrusion-centres, would find their natural place in the second class. These vents were due to an uprise of acid (rhyolitic) or intermediate (trachytic) magma. In their case, subsidence is also a recurring feature. But the subsidence consists in the foundering of the vent-walls, and, except in one case (Ardnamurchan, p. 31), does not appear to have a deep-seated significance. It is mainly (at least) the result of the removal of supporting material by the explosions. The instances cited below may have a useful bearing upon the difficulties which face the the investigator who is dealing with surface volcanicity, in his attempts to classify calderas.

An example of the foundering of wall-rocks into explosion-vents has been referred to above from Slieve Gullion. The downward movements and the foundered blocks were evidently both of a large order of magnitude. A still more remarkable instance comes from the Island of Arran (Fig. 10). The central vent of Arran includes vent-agglomerates and, in addition, ring-like intrusions which are

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[1]) See, for example, J. J. Richards, *Déformations locales de l'écorce terrestre et formation de calderas par effondrement*, Bulletin volcanologique, Nos. 27 à 30, 1936, pag. 40.

partly of later date than the agglomerates, and which bear a certain resemblance to ring-dykes. For this reason the term, « Central Ring Complex », has been applied by Dr. Tyrrell to the central vent as a whole. Now, with the vent-agglomerates there are associated large masses of elongate or irregular shape which are composed of country rocks. These country rocks within the vent come from much higher stratigraphical levels than the rocks (mainly

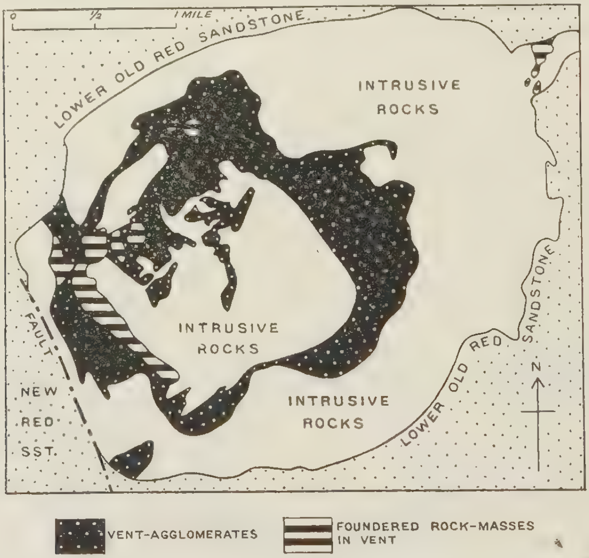

Fig. 10. — Sketch Map of the Central Vent of Arran, Scotland.
(Re-drawn, with permission, from Pl. IV, The Geology of Arran, Mem. Geol. Surv. Scotl., 1928).

Lower Old Red Sandstone) through which, at the present level of observation, the vent-complex is drilled. They belong to the Trias, Rhaetic, Jurassic, and Upper Cretaceous systems, and also include Tertiary olivine-basalt lavas (lower group of Mull). As B. N. Peach realized many years ago when the Island of Arran was being mapped by W. Gunn, the masses have slipped down into the vents from their original position for some thousands of feet. This fact is evident from the table of thicknesses given

below. It will be seen that for the foundered basalt lavas a minimum subsidence of about 4,000 feet may be estimated.

Tertiary olivine-basalt lavas	Not present *in situ* in Arran. In Mull, 3,000 feet.
Upper Cretaceous, Jurassic and Rhaetic	Not present *in situ* in Arran. In Antrim, N. Ireland, nearly 400 feet.
Trias	In Arran, at least 1,000 feet.
Permian	In Arran, 2,000 feet.
Carboniferous	Thin or absent around the central vent of Arran.
Upper Old Red Sandstone	? 800 feet around the central vent of Arran.

It is to be noted from the map (Fig. 10) that the largest foundered mass occurs *within* outcrops of the vent-agglomerate. In such cases enlargement of the vent subsequently to the foundering appears to be indicated. A similar explanation was offered by Dr. A. Harker in regard to an explosion-vent near Broadford in the Island of Skye. This vent is drilled through Cambrian limestone, but it includes a number of elongate and slightly curved outcrops of Tertiary basalt lavas, which are enveloped in the agglomerates. Harker has suggested that periods of land-slipping of the vent-walls alternated with periods of renewed explosive activity, which led to the enlargement of the vent. As in modern explosive eruptions, the foundering may in itself have led to a revivification of the explosive activity.

In Ardnamurchan, truly enormous masses of the basalt lavas have foundered into the more than usually extensive explosion-vents belonging to the early centre (Centre 1. *See* Fig. 7). In this case it is surmised that the situation of the vents is due directly to deep-seated causes, and that in depth the vents may be underlain by intrusions of ring-dyke pattern. If so, the foundering may be

partly the result of ring fracturing, the origin of which is to be sought in the depths (*see* p. 23).

The Zonal Arrangement of the British Tertiary Volcanoes

A reference should be made to the general geographical disposition of the intrusive centres of the Scottish-Irish province. These occur along a roughly N.-S. line measuring 225 miles in length, from Skye in the north to Slieve Gullion and Carlingford in the south. This line of Tertiary volcanoes would appear to mark a zone of crustal weakness. As affording further evidence of it, it is to be remarked that many of the north-west basic dykes of the linear swarms turn southwards to follow this N.-S. direction, and to unite in this way the centres of Skye and Mull and of Mull and Arran.

It may not be merely a coincidence that the centres of Mull and Arran are situated just at the places where two great north-easterly faults cross the supposed N.-S. zone of weakness. The faults concerned are the Great Glen Fault and the Highland Boundary Fault, ancient fractures which traverse the whole of Scotland and along which tectonic seismic disturbances occur even at the present day.

A similar situation of great volcanoes where tectonic lines meet may be remarked in the volcanoes in the vicinity of Tokyo in Japan, where the north-north-westerly Huzi Volcanic Zone meets the main north-easterly zones of Japan itself.

ACKNOWLEDGEMENTS

The Director, H. M. Geological Survey of Great Britain, has given his consent to the publication of this paper. For permission to reproduce the illustrations, acknowledgements are due to the Council of the Geological Society of London (for Fig. 9), the Council of the Geological Society of Glasgow (for Fig. 6), and the Controller of His Britannic Majesty's Stationery Office (for the remaining text-figures and

for the Plates I & II). The photograph reproduced in Fig. 2, Pl. I is published for the first time with the Controller's permission, Crown copyright being reserved.

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PLATE I. EXPLANATORY NOTES

Three explosion-vents occur on Ben Hiant, Ardnamurchan (see Fig. 7, p. 16). The cliff of agglomerate shown on Plate I represents part of the infilling of the south-west vent, the wall of which has been eroded away at this point. Nearby, however, a fragment of the wall is left. It consists of flat-lying plateau basalt lavas resting upon pre-Tertiary sedimentary rocks. The junction between the wall-rocks and the flatly-disposed tuff-beds and agglomerates of the vent is vertical.

It is concluded that, first, a large cavity was formed by a stupendous explosion or series of explosions, which broke through the plateau basalts and through an earlier explosion-volcano, and that subsequently this cavity was filled in, layer by layer, with the products of succeeding eruptions. These products consist mainly of materials belonging to the vent itself — felspar-phyric basalt, trachyte, and more acid rocks. Fragments of the olivine-basalt lavas are abun-

dant only in the vicinity of the vent-wall, and represent a scree-breccia along the interior slope of the crater.

The beds of tuff occur at intervals of about 20 feet in the un-bedded agglomerates. They would appear to represent a later phase of an eruption, as tuff sometimes forms a matrix for the blocks in the upper portion of the underlying agglomerate. Since upwards of 1,000 feet of interbedded agglomerates and tuffs (and occasional andesitic pitchstone lavas) are exposed in the south-west vent, some 50 eruptions would be required to account for them.

The composition of the tuffs, which are often very fine in grain, is peculiar. They contain much sedimentary material, in addition to igneous material. The source of the sedimentary material can only be the sedimentary gneisses which underlie the Tertiary plateau basalts. The formation of the finely comminuted tuffs may possibly be the result of gas-erosion of the volcanic pipe, such as F. A. Perret recognized as due to an intermediate gas phase during the eruption of Vesuvius in 1906.

J. E. Richey — *Some Features of Tertiary Volcanicity in Scotland and Ireland.*

Fig. I. — View of cliff, showing a flat-lying bed of tuff interbedded with the agglomerate.
(Rep., with permission, from Pl. III, B, The Geology of Ardnamurchan, etc., Mem. Geol. Surv. Scotl., 1930.)

 (Photo. H. M. Geol. Surv. Scotl.)

Fig. 2. Near view of typical agglomerate, a land-slipped mass, from the cliff in the background.

AGGLOMERATES OF THE SOUTH-WEST EXPLOSION-VENT OF BEN HIANT, ARDNAMURCHAN, SCOTLAND.

Fig. 1. — A Linear Dyke-Swarm, along the south coast of Arran, Scotland. The dykes are seen as narrow reefs jutting out into the sea. Along this coast-section, the average individual width of the dykes is about 11 ½ feet, and their average distance apart is about 50 yards.

(Rep., with permission, from Pl. V, 1, The Geology of Arran, Mem. Geol. Surv. Scotl., 1929).

(Photo. H. M. Geol. Surv. Scotl.)

Fig. 2. — A portion of a Ring Belt of Cone-sheets, along the south coast of Ardnamurchan, Scotland. The cone-sheets are inclined at angles of about 40 degrees away from the observor. Along this coast-section, the average individual width of the cone-sheets is about 15 feet, and their average distance apart is about 9 yards.

(Rep., with permission, from Pl. IV, The Geology of Ardnamurchan, etc., Mem. Geol. Surv. Scotl., 1930).

E. M. ANDERSON
EDINBURGH

Cone-sheets and Ring-dykes: the dynamical explanation

(With 1 text-figure)

The term « central intrusions » might be applied to any system of dykes, sills, or inclined sheets which were known to be intruded from some definite centre. The present communication deals with two classes of such intrusions, which form arcuate outcrops, arranged in series, round more or less identical centres of curvature.

The two classes referred to are those which have been named cone-sheets and ring-dykes by E. B. Bailey (2). Cone-sheets were first definitely recognized in Skye by Harker. They were first described in Mull by W. B. Wright, who published a section showing their extreme abundance (6), and was followed by other members of the Scottish Geological Survey. Ring-dykes were first mapped by Nolan and others, in the Slieve Gullion district in Ireland, and they have been found to occur in Mull in large numbers. Both types of intrusion are well developed in Ardnamurchan. Similar structures also occur round three centres in Northern Ireland, where, as in the Ardnamurchan example, they have been described by J. E. Richey (4, 5).

The Scottish and Irish examples are in the meantime to be regarded as the types, but ring-dykes occur in South Africa, (Pilansberg), and round more than one centre in North America. What appears to be a system of very thick cone-sheets has been described by A. D. N. Bain in Nigeria (3), and it seems probable that, as investigation proceeds, the known cases of both types of intrusion will be increased.

Cone-sheets are typically comparatively narrow (3 to 15 metres) and very numerous. They incline towards their

centres at angles which vary from about 35° to 60°. Ring-dykes are fewer and wider (say 50 to 2000 metres), and are either vertical, or dip away from their centres at steep angles. The two classes are in several instances found to surround the same centre. Where they do so their relations are shown diagrammatically by Fig. 6 of Dr. Richey' s paper (p. 23).

In the Mull Memoir (2) an attempt was made by the present author to explain the two different types of intrusion by stresses set up in the rocks by fluid magma occupying a subterranean caldron. This cavity must be supposed to have a somewhat dome-shaped upper surface, while it may extend downwards to a considerable depth. Its apex is directly beneath the centre of the cone-sheet or ring-dyke system, at a distance from the original surface of only a few kilometres. The formation of cone-sheets may then be explained by supposing the magma to be under a pressure which is greater than that caused by « head » in the surrounding rocks. It will thus have a tendency to « lift its roof ». This may be dynamically expressed by saying that there is extra pressure, in a vertical direction, immediately above the dome. In the horizontal direction, however, there is a relief of pressure. This is analogous to the fact that there is tension, in the direction of curvature, along the walls of a boiler. In the present case the magma pressure is insufficient to give rise to tension, but the relief of pressure will follow surfaces which run parallel to the walls of the cavity, and will thus have an outward inclination, increasing with their distance from the apex (Fig. 1).

Under these circumstances intrusions of magma may form, and may penetrate into, fissures which are analogous to tension fractures. Their directions will be perpendicular to the « principal stress » in the rock which comes nearest to being an actual tension. They will thus be normal to the walls of the basin. There is however more than one set of surfaces which has this normal character. One set will radiate from the centre, and in this way one may explain the radial dykes which perhaps exist in Skye, and

certainly occur in one case in America. In the particular instance which is illustrated in Fig. 1. the closest approximation to a tension is usually in the plane of the diagram. In such a case the intrusions will not be radial, but will surround the centre in the form of cone-sheets. The inner

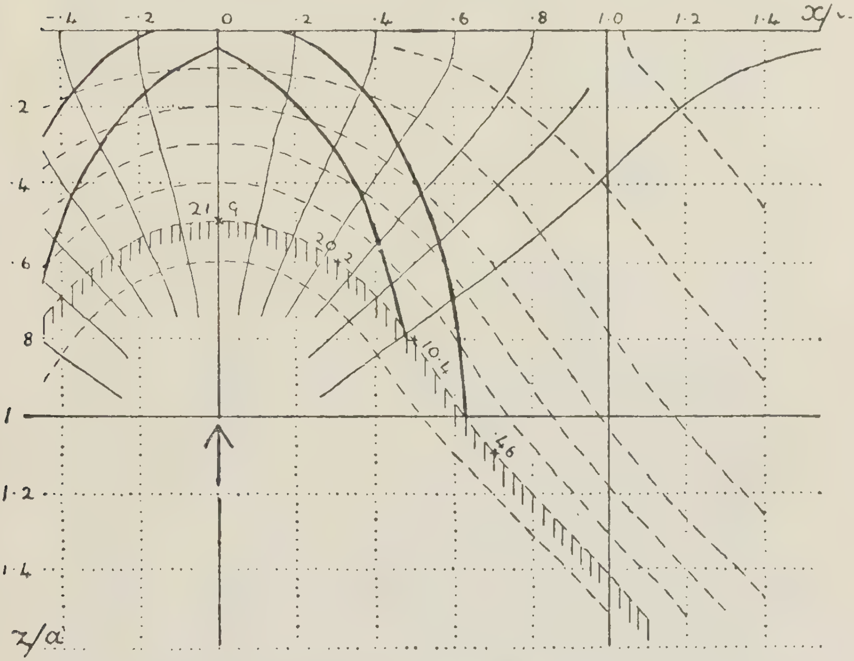

Fig. 1. — Formation of Cone-sheets and Ring-dykes. For explanation see text. Reproduced, with permission, from Proc. Roy. Soc. Edin., vol. 56, p. 144.

sheets of a system are sometimes the steeper, as shown by the text-figure.

Ring-dykes, of the other kand, were explained by supposing that, when they were formed, the pressure in the magma basin had sunk to below that normally due to gravity at an equal depth. In this case the fractures which are occupied are not directly formed by the magma, but only indirectly, owing to stresses produced in the rock. They are shear fractures, as opposed to tension fractures,

and the intrusions may, in some cases, be of somewhat later date. To produce any of the larger ring-dykes, however, there must be a rupture which forms a closed curve in horizontal section. This must extend downwards to the magma basin, and the block within it must, for some reason or other, be free to sink. According to te theory put forward, there is an outward inclination of this fracture. During subsidence the block therefore parts company with its surroundings, and the vacancy is simultaneously occupied by magma.

It would be incorrect to regard such an intrusion as due to suction. A fluid under gravity must always to some degree be under pressure. But in ring-dyke formation the pressure is less, just as in cone-sheet intrusion it is greater, than that usually characteristic of its level in the crust.

The suggestions put forward in the Mull Memoir, in 1924 were not at the time supported by any rigid mathèmatical theory. It was not until ten years later that formulae were found showing how, with certain shapes of basin, and certain distributions of pressure along their walls , the stresses necessary for cone-sheet and ring-dyke formation are bound to arise (1). The principal directions of stress given by one set of formulae are shown in Fig. 1. Here the shaded margin may be taken to be a vertical cross section of the edge of the magma basin. If there is excess of pressure in the caldron, there will be a relative tension which is greatest across the surfaces indicated by the fine firm lines, with consequent production of cone-sheets in these directions. If there is defect of pressure in the basin, there will be relative tension across the surfaces whose intersection with the plane of the diagram is given by the broken lines. There has not, however, been intrusion of magma along these surfaces. The heavy lines are drawn at angles of about 25° to the broken lines, and are intended to represent the course of possible shear fractures. In their lower parts, at least, they correspond in inclination with ring-dykes.

Many difficulties, of course, remain. It is impossible as yet to say why in some circumstances a rock, or any

other solid, will yield by shear fracture, and in other cases by tension fracture. Both types do exist in the crust, as the one class is exemplified by faults. and the other by ordinary dykes. It has also been objected that the systems of stress given by the formulae only occur before rupture. When even a single fracture has been formed, a system will be more or less modified. This is true, but the accordance of fact with theory is so good that the first stage of an explanation would seem to have been reached.

The shape of caldron shown in the diagram, with the relative pressures indicated along its margin, form a system which lends itself to calculation. This system is not however regarded as being actually the most probable. Certain difficulties may be avoided if the basin has more nearly the form of an « inverted flower-pot », with a somewhat angular edge. The variations of pressure in the basin may perhaps be explained as follows. One may suppose the caldron to open downwards into a shallow horizontal reservoir, of great lateral extent. Within such a reservoir pressure will be determined almost solely by the weight of the overlying rock. It will therefore be neither in « excess » nor in « defect ». Suppose however that the magma in the caldron is lighter than the rock which surrounds it. Molten basalt at the surface has a density of apout 2.59, so that this may well be the case. There will then be a smaller vertical gradient of pressure in the magma than in the rock. It follows that there will be « excess » of pressure in the magma basin, increasing towards the top. The defect of pressure which leads to ring-dyke formation may be explained most easily by a reduction of the volume of the magma. This may perhaps be caused by cooling, with partial consolidation. In order that this may be effective there must be elimination of the conditions which would lead to excess of pressure, and this may happen if the consolidation interrupts the continuity of the supposed horizontal reservoir.

Thanks are due to the Council of the Royal Society of Edinburgh for permission to reproduce the text-figure.

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The Carboniferous and Permian volcanoes of Scotland

(With 3 Text-Figures and 5 Plates)

CONTENTS

Introduction

Scottish Palaeozoic volcanoes became widely known forty years ago, on the publication of Sir Archibald GEIKIE's « Ancient Volcanoes of Great Britain ». GEIKIE described in masterly fashion the long and complicated succession of volcanic episodes and incorporated in his account a good deal of petrological detail. The scenery of the volcanic districts and the structure of lava plateau, volcanic neck, dyke, and sill, so well displayed on hillside and coastline, were clearly described, and illustrated by admirable sketches and photographs.

Since that time the products of the Carboniferous and Permian eruptions, particularly in the Midland Valley of Scotland, have been studied almost continuously in field and laboratory. Many new facts concerning their distribution, petrography, and chemistry, and the conditions that prevailed at the time of the eruptions, have appeared in

Geological Survey publications and in the Transactions of learned Societies.

It is thus the purpose of the present paper to summarize the results of over 150 years of volcanological research, initiated in Edinburgh by James HUTTON (1726-1797) one of the founders of modern geology.

The Main Periods of Eruption

The bulk of the lavas and tuffs are found in the Calciferous Sandstone Series, the lowest subdivision of the Carboniferous System [1]). In different places they are equivalent to stratigraphical horizons ranging from sub-zone C_1 to sub-zone D_2 (in part) of Vaughan's Avonian classification. A few flows are locally intercalated in what are regarded as the uppermost beds of the conformably underlying Upper Old Red Sandstone (e. g. Campsie Fells, in the Midland Valley, Fig. 1 : near Greenlaw in the Southern Uplands, Fig. 2). Lower Carboniferous volcanicity was continued (in sub-zones D_2 and D_3) until late in Carboniferous Limestone times in the Bathgate Hills and in Fife (Fig. 1), and was renewed locally at the close of the Millstone Grit period (Lancastrian [2])), notably in the Firth of Clyde area. No lavas or tuffs are intercalated in the rest of the Upper Carboniferous strata (Coal Measures : Yorkian and Staffordian [3])), but volcanoes were again active at an early stage of the deposition of the succceding Permian Sandstone.

These eruptions brought to a close the volcanicity that had characterized much of Carboniferous and Permian time. Scotland was not again to be the scene of volcanic action until the initiation of the great Tertiary (Eocene) outburst, of which there is impressive evidence in the lava cliffs and volcanic mountains of the western coastline of our Highlands.

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[1]) For information on Carboniferous System see M. MACGREGOR, « Scottish Carboniferous Stratigraphy », Trans. Geol. Soc. Glasgow, vol. XVIII, part III, 1931, pp. 442-558.

[2]) For definition see M. MACGREGOR, op. cit., p. 483.

[3]) For definition see M. MACGREGOR, op. cit., p. 483.

Distribution of Volcanic Rocks and their Influence on Scenery

Carboniferous and Permian igneous rocks are, in Scotland, almost entirely confined to the Midland Valley and Southern Uplands. The Permo-Carboniferous quartz-dolerite dykes (p. 54) are perhaps the only exceptions ; they cross the Highland Boundary Fault and traverse the schists to the north-west (Fig. 3). Dykes of camptonite and monchiquite that are numerous in the schists and gneisses of certain parts of the Western Highlands, and extend northwards as far as the Orkneys, may possibly be of Permian or Permo-Carboniferous age. Some of them are younger than quartz-dolerites, however, and it has not yet been conclusively demonstrated that they are pre-Mesozoic in age, and therefore unconnected with Tertiary volcanicity.

Midland Valley. — The hill features of the diversified scenery of the Midland Valley of Scotland are almost entirely due to the presence of resistant Palaeozoic igneous rocks in association with softer sediments of Old Red Sandstone and Carboniferous age. Ranges of hills and high moorland plateaus are formed of lava sequences, while smaller eminences are due to volcanic necks and sills. With some of the main volcanic ranges, such as the Sidlaw, Ochil, and Pentland Hills, we are not concerned, for they are built up of lavas and tuffs off Lower Old Red Sandstone age. The Carboniferous lavas and tuffs are, however, even more important as scenic elements. This statement applies more particularly to the volcanic rocks of Calciferous Sandstone age ; they form the Campsie Fells (which along with the Gargunnock, Fintry, and Kilpatrick Hills extend from Stirling to the River Clyde), the Greenock-Ardrossan Uplands, the Beith-Eaglesham-Strathaven Uplands, the Garleton Hills, etc. (Fig. 1). The Clyde Lava Plateau, in the west, was estimated by Geikie to have been about 3000 ft. thick, and to have covered between 2000 and 3000 square miles. Lavas and tuffs of Carboni-

ferous Limestone times are not of much importance as scenic elements, but they form the somewhat elevated ground near Linlithgow, known as the Bathgate Hills. The outcrops of lavas of Millstone Grit age are mainly in Ayrshire, where they appear as a narrow interrupted band forming minor scenic features on the north and south margins of the Ayrshire coal basin; they also form outcrops within the Coalfield, near Troon. Other small occurrences are known, in the island of Arran and in Kintyre [1]). In Fife certain minor olivine-basalt outcrops are now believed to represent lavas of Millstone Grit age. The total area occupied by outcrops of interbedded Carboniferous volcanic rocks exceeds 550 square miles.

Permian lavas and tuffs occupy an area of only 13 square miles; they form a narrow annular outcrop around the overlying Permian Sandstone of the Mauchline Basin in Ayrshire. Numerous Permian volcanoes are, however, represented by volcanic necks both in the west (Ayrshire) and in the east (Fife).

The present distribution of the Carboniferous and Permian lavas is mainly the result of profound Tertiary and Glacial erosion acting on strata affected by comparatively gentle folding (largely of Permo-Carboniferous age) and by extensive faulting.

Trap featuring is, as a rule, well developed in the Carboniferous lava plateaus, as for instance in the Campsie Fells area (Plate II, Fig. 1). Locally, however, the lava scarps are largely obliterated owing to the effects of complex faulting, Glacial erosion, the deposition of boulder clay, etc. The lava plateaus form rather bleak, wet and peaty moorlands, widely given over to grouse-shooting. At the same time they produce enough grass to support large numbers of sheep.

The volcanic necks characteristically form isolated conical to dome-shaped hills (Plate I, Fig. 2). Those filled with basic agglomerate often give rise to rich soil that

[1]) Arran and Kintyre lie to the west of the area shown in Fig. 1.

supports good grass (hence Geikie's « green hill » type of Permian vent ; Plate IV, Fig. 2). Those filled entirely with solidified lava usually form craggy eminences ; good examples are the Castle Rock of Edinburgh, and Dumbarton Rock on the River Clyde.

The sills often give rise to prominent rocky cliffs, such as the quartz-dolerite crag on which Stirling Castle stands, and the great teschenite escarpment that dominates the city of Edinburgh (Plate I, Fig. 2).

Southern Uplands. — Much of the Southern Uplands of Scotland is formed of hilly or even mountainous country carved out of steeply folded Ordovician and Silurian strata, and igneous intrusions predominantly of Lower Old Red Sandstone age. The Carboniferous volcanic rocks that locally occur in this region, in a belt of country extending from the neighbourhood of St Abb's Head to the Solway Firth (Fig. 2), do not therefore dominate the scenery as they do in the Midland Valley. Lavas occur at the base of the Carboniferous in Berwickshire and Roxburghshire (« the Kelso traps »), in Dumfries-shire (Birrenswark Hill), and in Kirkcudbrightshire (Kirkbean Glen, S. W. of the Nith estuary). They are also found near the top of the Calciferous Sandstone Series in Dumfries-shire (Glencartholm). None of these volcanic groups exceeds 200 to 300 ft. in thickness. Within this region, which includes Tweeddale, Teviotdale, Eskdale, and Liddisdale, quite a number of Lower Carboniferous volcanic necks and small igneous intrusions are also found. These rocks, as well as the lavas, give rise to hills that form well known landmarks.

Millstone Grit lavas are represented to the south of the Southern Upland fault only by a thin flow, associated with Carboniferous sediments, on the western edge of the Permian outlier near Stranraer.

In the Southern Uplands, basal Permian lavas are found in the Carboniferous-Permian outliers of Dumfries-shire, at Thornill, and at Sanquhar were they are associated with a few volcanic necks. The Thornhill outcrop is the most extensive, but it forms only a narrow band, not more

than 150 ft. in thickness, appearing from below Permian sandstone, and has little influence on the local scenery.

Nature and General Sequence of Volcanic Rocks

Lower Carboniferous Eruptions. — Central and Southern Scotland in Carboniferous times formed a petrographical province in which the eruptive rocks belong to the alkaline (sodic) magma series. The great bulk of the eruptive products consisted of various kinds of alkaline olivine-basalt. The following types have been recognized :

Macroporphyritic basalts (with many large phenocrysts)

Markle type : with phenocrysts of labradorite and olivine.
Dunsapie type : with phenocrysts of labradorite, olivine and augite.
Craiglockhart type : with phenocrysts of olivine, and augite.

Microporphyritic basalts (with many small phenocrysts)

Jedburgh type : with phenocrysts of labradorite and olivine.
Dalmeny type : with phenocrysts of olivine, and sometimes sporadic labradorites and augites.
Hillhouse type : with phenocrysts of olivine and sometimes of augite.

The main groundmass constituents are labradorite, augite and iron-ore in all cases except the Hillhouse type, in which they are augite, iron ore and a little labradorite, with much analcite or glass. Analcite is often present in small amount in other types.

Most interesting examples of composite basaltic lava flows, porphyritic above (Markle type) and non-porphyritic below (basaltic mugearite) have recently been recognized. Locally trachybasalts (mainly mugearites), trachyandesites, trachytes, and rhyolites, also formed lava flows. Some of the associated intrusive sills, laccoliths, plugs, and dykes, are composed of similar rocks, while others consist of teschenite, basanite, monchiquite, phonolite (and phonolitic trachyte), riebeckite-felsite, etc. Intrusions of plutonic character are unknown.

In several areas, notably in the Garleton Hills, in the Beith-Eaglesham- Strathaven Uplands, in part of the Greenock-Ardrossan Uplands, and in the Campsie Fells, the earlier basaltic and mugearitic lavas were succeeded towards the end of Calciferous Sandstone volcanic activity by leucocratic alkaline and acid rocks which formed lavas, tuffs or intrusions. Olivine-rich basalt lavas were however poured out again in Carboniferous Limestone times, as a continuation of basaltic volcanicity of Calciferous Sandstone date, in Fife and in the Bathgate Hills, and at the close of Millstone Grit times in the Firth of Clyde area. Moreover basaltic intrusions cut the agglomerates of some of the trachytic vents. Thus in the latest Carboniferous eruptions there appears to have been almost everywhere a reversion to basaltic magma.

The main areas of trachytic and trachyandesitic lavas, tuffs, and intrusions, are in the Garleton Hills district in the east, and in the Beith-Eaglesham-Strathaven Uplands in the west, but some leucocratic alkaline lavas are found in Bute, and in Kintyre where they are accompanied by trachytic intrusions.

Plugs and sills of phonolite and phonolitic trachyte (Plate III, Fig. 1) are known both in the Midland Valley and in the Southern Uplands. Intrusions of riebeckite-trachyte and riebeckite-felsite are confined to the Southern Uplend area. All these nepheline- and riebeckite-bearing rocks are believed to belong to a late phase of Calciferous Sandstone activity.

It should perhaps be emphasized for the benefit of foreign readers that fresh material for the microscopic study of these Palaeozoic volcanic rocks can, as a rule, be obtained without any difficulty. The only rocks that are habitually highly altered are the rhyolites and some of the felsites. The state of preservation of many of the basaltic rocks is quite comparable to that of the Tertiary basalts of western Scotland. It was the early recognition of this fact that made it impossible for British petrologists to

ccept Continental rock-classifications involving « Palaeovolcanic » and « Neovolcanic » groupings.

In this connection it is interesting to recall that the discovery of nepheline in the Garleton Hills area in 1892, one of the first records of this mineral in a Palaeozoic volcanic rock, had a decided influence on Continental rock-classification. Hatch, who initiated the petrographic description of Scottish Carboniferous igneous rocks on modern lines, recognized the alkaline character of the Garleton Hills lavas and, in conjunction with Rosenbusch the great German petrographer, established the presence of nepheline in the Traprain Law phonolite laccolith. He thus proved the existence of Palaeozoic volcanic rocks similar in all respects to alkaline types which, up to that time, had been recognized only in the younger volcanic districts. In consequence Rosenbusch became convinced that the age-classification of volcanic rocks has no real petrographical significance.

The volcanic necks are found cutting the lava plateaus and also, denuded to lower levels, in the adjacent older sediments that are now exposed at the surface owing to folding and erosion. Corresponding to the fact that the basaltic lavas greatly preponderate over the trachytic flows, necks filled with basic materials are much more abundant than those of trachytic nature. The necks are usually circular to oval in outline, and as a rule do not exceed a quarter of a mile in diameter. One of the best known and most completely preserved, a composite vent about half a mile across, forms Arthur's Seat in the city of Edinburgh (Plate I, Fig. 2). Lavas and tuffs are preserved here in contact with the vent-agglomerates. All details of volcanic structure are magnificently exposed, and natural sections even show the sedimentary floor over which the first lavas flowed. Small though it is, this is probably the world's most instructive example of a dissected volcano, for it is readily accessible, and successive generations of geologists have worked out minute details of the various phases of its eruptions.

Millstone Grit Eruptions. — The lava flows poured out in Millstone Grit times were almost all microporphyritic olivine-basalts of Dalmeny type.

Permian Eruptions. — The lavas of the Permian eruptions are mainly olivine-rich basalts very similar to the Dalmeny basalts of the Carboniferous, but analcite- and nepheline-basanites, and nepheline-monchiquites (« nepheline-basalts »), have also been recorded. The Permian eruptions on the whole perhaps tended to produce basic magma that was rather more alkaline than that of Carboniferous times.

The igneous fragments in the agglomerates of the Permian necks of Ayrshire include blocks and lapilli of lava or Permian types, and fragments of basic alkaline sills. Blocks and nodules of carbonated peridotite, and fragments of large crystals of alkali-feldspar, augite, hornblende, and biotite, are also of frequent occurence. Similar peridotite (or pyroxenite) and crystal fragments are, however, characteristic of the agglomerates and monchiquite intrusions of volcanic necks in Fife, some of which are of Lower Carboniferous age.

Conditions of Eruption

Calciferous Sandstone Times. At the beginning of Calciferous Sandstone volcanicity, or very shortly afterwards, there were, in many districts, explosive basaltic eruptions that produced beds of tuff; but after this opening phase the ejection of tuff was quite subordinate to the formation of lava flows. The basic lavas of the period, poured out subaerially from scattered pipe-like vents that were occasionally aligned as if following a line of crustal weakness (Plate I, Fig. 1), coalesced to form volcanic plateaus, in places 2000 to 3000 ft. in aggregate thickness (Clyde Plateau). Individual flows frequently show rotted upper surfaces, and development of « bole », characteristic of lavas subjected to contemporaneous weathering. Although locally some flows were erupted on the

margins of lagoons and were soon covered by water, not a single example of a pillow lava has been found. Lava surfaces were of the clinkery or « aa » type, and no « pahoehoe » lava has ever been recorded.

Climatic conditions were probably semi-arid when the majority of the eruptions took place. Only very occasionally did the sea gain access to the lava fields. The volcanoes are believed to have spread out their lavas and tuffs on a low-lying and somewhat unstable flat terrane on which there were inland sheets of water subject to periodic dessication. Locally, and very exceptionally, lavas were subjected to lateritic weathering conditions that resulted in the formation of bauxitic clays (Kintyre and Ayrshire ; cf. p. 51).

The products of the trachytic eruptions of the close of Calciferous Sandstone volcanicity included thick lava flows, occasionally showing slaggy to brecciated tops, as well as beds of trachytic tuff. Extensive outcrops of these tuffs are preserved in the Eaglesham district (Plate II, Fig. 2). Some of the material is coarse agglomerate containing blocks of trachyte up to several feet in diameter, and thus indicates violent explosive action. In the Beith-Eaglesham-Strathaven area the trachytic rocks are restricted to a comparatively narrow west-north-westerly belt, and are closely associated with numerous trachytic vents (plugs). It would appear that in this area the distribution of trachytic eruptive foci was determined by a deepseated west-north-westerly zone of crustal weakness. At least one trachytic outcrop of the district (Drumboy Hill) seems to represent an eruptive « dome » (quellkuppe).

There is clear evidence that after the close of this volcanic episode the lavas were subjected to prolonged denudation. The strata of the Calciferous Sandstone Series rest on the lavas with marked unconformity, and the first sediments to be laid down were composed of volcanic detritus containing pebbles derived from trachytic and basaltic lavas.

Carboniferous Limestone Times. — In the later eruptions of the Lower Carboniferous the ejection of basic tuffs was more prevalent at the lava-forming volcanoes. (e. g. Bathgate Hills), and in a number of places explosive vents produced nothing but tuffs. Some of the volcanoes of this period probably formed marine islands, or fringed the shores of the fluctuating Carboniferous Limestone seas.

Millstone Grit Times. — The unusual type of decomposition exhibited by the olivine - basalt lavas of Millstone Grit times, which in Ayrshire have a maximum aggregate thickness of about 550 ft., has provided interesting evidence of the physical conditions that prevailed during and after the eruptions. Beds of sandstone, fireclay, and poor coal, are interbedded with the lavas. It would appear that the flows were erupted over almost flat swampy areas subject to intermittent subsidence. Between periods of eruption sedimentary material was sometimes laid down in water ; at other times, under humid conditions, forest growth was temporarily established on the lava surfaces. As a result of chemical changes due to the leaching action of surface waters between successive eruptions, the flows show every stage of alteration from fresh olivine-basalts, through highly decomposed but still recognizable basalts, to residual material in which iron (as sphaerosiderite etc.) and alumina (as kaolinite etc.) are concentrated. At the close of the eruptive period the land surface remained more or less stable for a considerable time and leaching processes attained a maximum. Between the iron-impregnated top of the last lava and the overlying Coal Measures, there were formed layers of somewhat variable bauxitic clay, up to about 6 ft. in total thickness. This brittle aluminous clay ($Al_2 O_3$ over 50 per cent) appears to represent in part residual altered basalt, and in part kaolinized basaltic debris, bauxitized sediment, and chemical precipitates, deposited in shallow lagoons which were situated on the lava surfaces and were subject to dessication.

It has not been found possible to assign definitely to the Millstone Grit period any of the basic volcanic necks that are found near the lava areas. This is due to the resemblances between the olivine-basalts of Millstone Grit eruptions and the Lower Carboniferous and Permian basalts of Dalmeny and allied types. The Millstone Grit lavas, which are in many places only 50 to 150 ft. in total thickness, were however almost certainly erupted from scattered volcanic vents, and coalesced to build up a more or less continuous, if rather attenuated, plateau in the Clyde area. There is reason to believe that the lavas extended southwards to Stranraer in the Southern Uplands, and west-south-westwards as far as Ballycastle in Northern Ireland. Thus the total area affected by the Clyde Millstone Grit eruptions was possibly about 2400 square miles in extent.

Permian Times. — When volcanoes became active again at the beginning of Permian times climatic conditions were very different. The volcanic sequence, which locally in Ayrshire attains about 500 ft. in thickness, rests unconformably on the Carboniferous, and is overlain by the Mauchline Sandstone, a typical red desert sandstone with wind-rounded « millet-seed » quartz grains and large scale dune-bedding. There is abundant evidence that desert conditions reigned throughout the eruptive period. Locally either tuff or desert sandstone intervenes between the Carboniferous and the lava sequence, and in some places tuffs with interbedded desert sandstone separate the lavas from the overlying Mauchline Sandstone (Plate IV, Fig. 1). Millet-seed sandstone is also interbedded with the lava flows ; it often penetrates their slaggy tops and is frequently mixed with the igneous fragments of the tuffs. Moreover the presence of isolated wind-rounded quartz grains is a characteristic feature of the agglomerates of many of the Permian necks.

There is no doubt that the Permian lavas and tuffs, like those of the Carboniferous, were erupted from scattered vents, and coalesced to form plateau-like accumula-

tions of no great thickness. The lavas and tuffs probably once covered a very extensive area, for Permian volcanic vents have a wide distribution in the Midland Valley. Profound erosion since early Tertiary times has however almost completely removed the stratified volcanic rocks, the overlying desert sandstone and any Mesozoic or younger beds that may once have extended over much or all of central and southern Scotland. There are over sixty Permian necks in the Central Ayrshire Coalfield, scattered over a wide area around the fragmentary relic of the Permian lavas preserved in the Mauchline basin. No neck cuts the Mauchline Sandstone and only three penetrate the lavas. The others, as now exposed, are more deeply denuded, and pierce Carboniferous sediments at various lower stratigraphical levels.

Sills and Dykes

In the Lower Carboniferous sediments and to a lesser extent in the Upper Old Red Sandstone, there are a good many intrusions that correspond closely in type to the various kinds of basic and acid lavas. They are found in close association with Lower Carboniferous lavas, and, although they sometimes cut through the flows, there is no doubt that they are roughly contemporaneous with them.

There are, however, in addition to these, two very distinctive sets of intrusions, the teschenite- -theralite suite and the quartz-dolerite- -tholeiite suite, that were intruded into the Upper Carboniferous (Coal Measures) as well as into Lower Carboniferous strata, and differ considerably from any of the lavas in petrological type (Fig. 8).

Types corresponding to lava-form Rocks. — The Lower Carboniferous dykes are of little importance; they rarely exceed 12 ft. in thickness, and individual intrusions cannot be traced far. In type they correspond to various basic and acid lavas in or near which they occur.

Sills and laccoliths similar to basaltic, trachytic or rhyolitic lavas are much more prominent. Leucocratic al-

kaline types are the more numerous. A few of the intrusions, composed of layers of different kinds of rock, provide excellent examples of composite sheets (e. g. St. Leonard's basaltic sill, Edinburgh ; the Eildon Hills trachytic laccolith, Melrose, Plate III, Fig. 2).

The Teschenite - Theralite Suite. — Rocks of this suite [1]) occur almost exclusively as sills which range up to 280 ft. in thickness (Plate V, Fig. 1). They are so numerous that it has been claimed that the Midland Valley of Scotland is one of the most notable districts of the world for the study of rocks of this kind (Fig. 3). They include alkaline dolerites, teschenites, essexites, theralites, basanites, picrites, bekinkinites and peridotites. Monchiquites occur also as dyke and small sills. Composite sills with basic to ultrabasic layers have been intensively studied. Some of the intrusions in the east are of Lower Carboniferous age, but many of those in the west cut Coal Measures and are genetically connected with the Permian volcanic episode.

The Quartz-dolerite- - Tholeiite Suite. — One of the most striking features of the geological map of central Scotland is the presence of a set of broad (60 to 150 ft.) dykes of quartz-dolerite and tholeiite, with a general E.-W. trend (Fig. 3), that have been traced for long distances (up to 180 miles) In certain districts, notably in Fife, in the Lothians, and in Stirlingshire, the dykes are accompanied by great sills of quartz-dolerite (Plate V, Fig. 2), up to 300 ft. in thickness, to which they acted as « feeders ». In two instances in eastern Scotland teschenite sills are cut by quartz-dolerite dykes. Various lines of evidence lead to the conclusion that the dykes and sills are of Permo-Carboniferous age, and were intruded in late Carboniferous times, or early in the Per-

[1]) « Suite » here means « an assemblage of allied rock-types ». Many, but not necessarily all, of the types have close genetic connections. For these alkaline rocks, at least two main lines of descent have been postulated.

mian period before some at least of the Permian volcanoes became active.

Conclusion

We have now reviewed in the briefest fashion the main facts relating to Scottish Carboniferous and Permian volcanicity. For a more detailed summary the reader is referred to two recently published Geological Survey handbooks of the British Regional Geology series (see « References », below). One of these, dealing with the Midland Valley of Scotland, gives petrological details regarding the most important and most intensively studied volcanic district. The other summarizes our less extensive knowledge of the volcanicity of the south of Scotland (Southern Uplands). Both volumes contain comprehensive bibliographies. Information regarding the Carboniferous and Permian rocks of Arran is best obtained from the Geological Survey memoir on that island. The Carboniferous volcanic rocks of Kintyre are dealt with in two papers referred to below. The Arran and Kintyre references are of purely local interest, but are included for the sake of completeness ; the localities concerned are not dealt with in the two Regional handbooks. A reference is also given below to a paper by J. S. Turner. This useful summary of Carboniferous volcanicity in north-western and central Europe deals with the igneous rocks of (i) the Variscan Geosyncline and (ii) the Variscan Foreland, including Scotland.

Up-to-date exhibits comprising specimens, maps, diagrams, and photographs, and specially designed to illustrate the geology and volcanicity of the areas described in the two Regional handbooks, are to be seen in the new Museum of Practical Geology opened in London in 1935. Numerous maps, models, and specimens, illustrative of Scottish volcanicity, are also displayed in the Royal Scottish Museum, Edinburgh. A large scale model of Arthur's Seat volcano is a noteworthy exhibit.

No attempt will be made here to mention all the geologists who have helped to build up our knowledge of of the Carboniferous and Permian volcanic rocks of Scotland. In addition to very early pioneers such as James Hutton and Sir James Hall of Dunglass, the following have been outstanding: Allport, Ami Boué, Hay Cunningham, Cuthbert Day, Sir A. Geikie, Goodchild, Hatch, Judd, Charles Maclaren, Peter MacNair, B. N. Peach, Skipsey, Stecher, Teall, and Ferdinand Zirkel. The names of many workers who are still alive will be found in the bibliographies referred to above; among them Prof. W. W. Watts, Sir J. S. Flett, Prof. E. B. Bailey, Dr. G. W. Tyrrell, Mr. D. Balsillie, and Dr. R. Campbell are especially prominent.

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Explanation of Plates

(The photographs are reproduced, by permission of the Controller of H. M. Stationery Office, from negatives in the official Scottish Collection of the Geological Survey of Great Britain).

PLATE I.

Fig. 1. — Line of volcanic necks of Lower Carboniferous age, at edge of lava plateau, Campsie Fells. The lava plateau is to the right of the line of necks. Sediments, appearing from below the lavas, form the lower slopes to the left of the necks. These strata, like the lavas, are of Calciferous Sandstone age. (Negative C2111).

Fig. 2. — Arthur's Seat and Salisbury Craigs, Edinburgh, from the south. Arthur's Seat, on the right, is a composite volcanic neck of Lower Carboniferous age. Salisbury Craigs, on the left, are formed by a thick sill of teschenite intruded at the top of the Upper Old Red Sandstone, which forms the scree slopes below the escarpment and much of the foreground. (Negative B927).

PLATE II.

Fig. 1. — Lower Carboniferous basalt lava escarpments, near Fintry, Campsie Fells area. These flows belong to the Clyde Lava Plateau. Carboniferous sediments, appearing from below the lavas, form the lower slopes of the hill. (Negative C2122).

Fig. 2. — Bedded trachytic tuff of Lower Carboniferous age, near Eaglesham, Renfrewshire. Note the contemporaneous local disturbance of bedding, produced by the fall of one large block of trachyte. (Negative C2945).

PLATE III.

Fig. 1. — The Bass Rock, East Lothian coast, Firth of Forth. A Lower Carboniferous plug of phonolitic trachyte. The precipitous cliffs of the Bass serve as a breeding place for innumerable seabirds. (Negative B552).

Fig. 2. — Eildon Hills, near Melrose in the Southern Uplands. These hills have been carved by erosion out of a composite trachytic laccolith, of Lower Carboniferous age, that was intruded into Upper Old Red Sandstone resting unconformably on Silurian (foreground). Old Red Sandstone below the laccolith has been protected from erosion, and forms a narrow outcrop around its base. (Negative C3486).

PLATE IV.

Fig. 1. — Desert sandstone overlying Permian tuffs, River Ayr, near Mauchline, Ayrshire. Although the junction between sandstone and tuff appears to be very sharp, the tuff is full of grains of wind-rounded quartz sand. (Negative C2918).

Fig. 2. — Patna Hill, River Doon, Ayrshire. A very typical Permian agglomerate-filled neck, which forms a low domeshaped hill covered with grass. This Permian neck is profoundly eroded. It cuts Lower Carboniferous sediments (foreground), in an area where there are no volcanic rocks interstratified in the Carboniferous. (Negative C2905).

PLATE V.

Fig. 1. — Permian sill of theralitic essexite, Hillhouse Quarry, near Troon, Ayrshire. The development of columar jointing is here more perfect than is usual in Scottish sills. The alkaline sills, like the quartz-dolerites, are widely quarried for use as road-metal, paving setts or kerb stones. (Negative C2908).

Fig. 2. — Base of Permo-Carboniferous quartz-dolerite sill, Hound Point, Firth of Forth, near Edinburgh. Note how bedded sandstone below the sill has been ruptured and bent upwards during the intrusion of the sheet of molten dolerite. The sandstone has been indurated, and the dolerite has a fine-grained « chilled margin » at the contact. (Negative C608).

G. Macgregor — *The Carboniferous and Permian volcanoes of Scotland.*

Fig. 1.

Fig. 2.

Fig. 1.

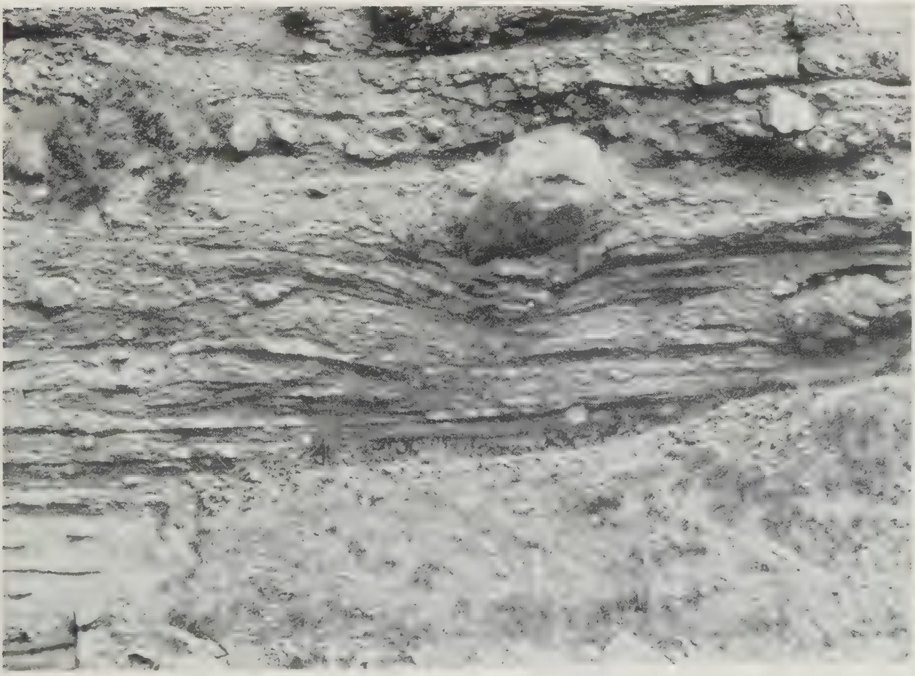


Fig. 2.

Fig. 1.

Fig. 2.

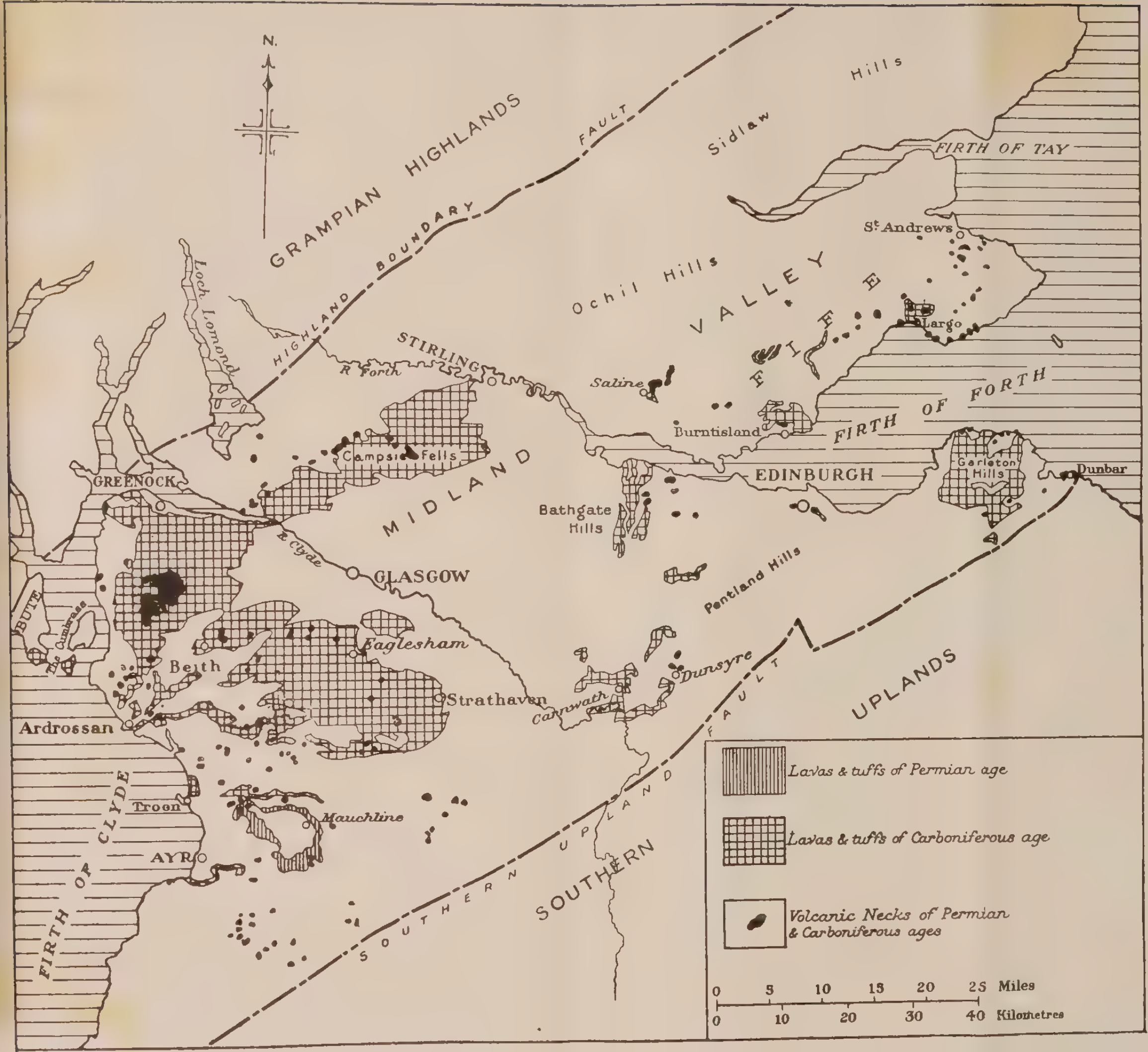
., G. Macgregor — *The Carboniferous and Permian volcanoes of Scotland.*

Fig. 1.

Fig. 2.

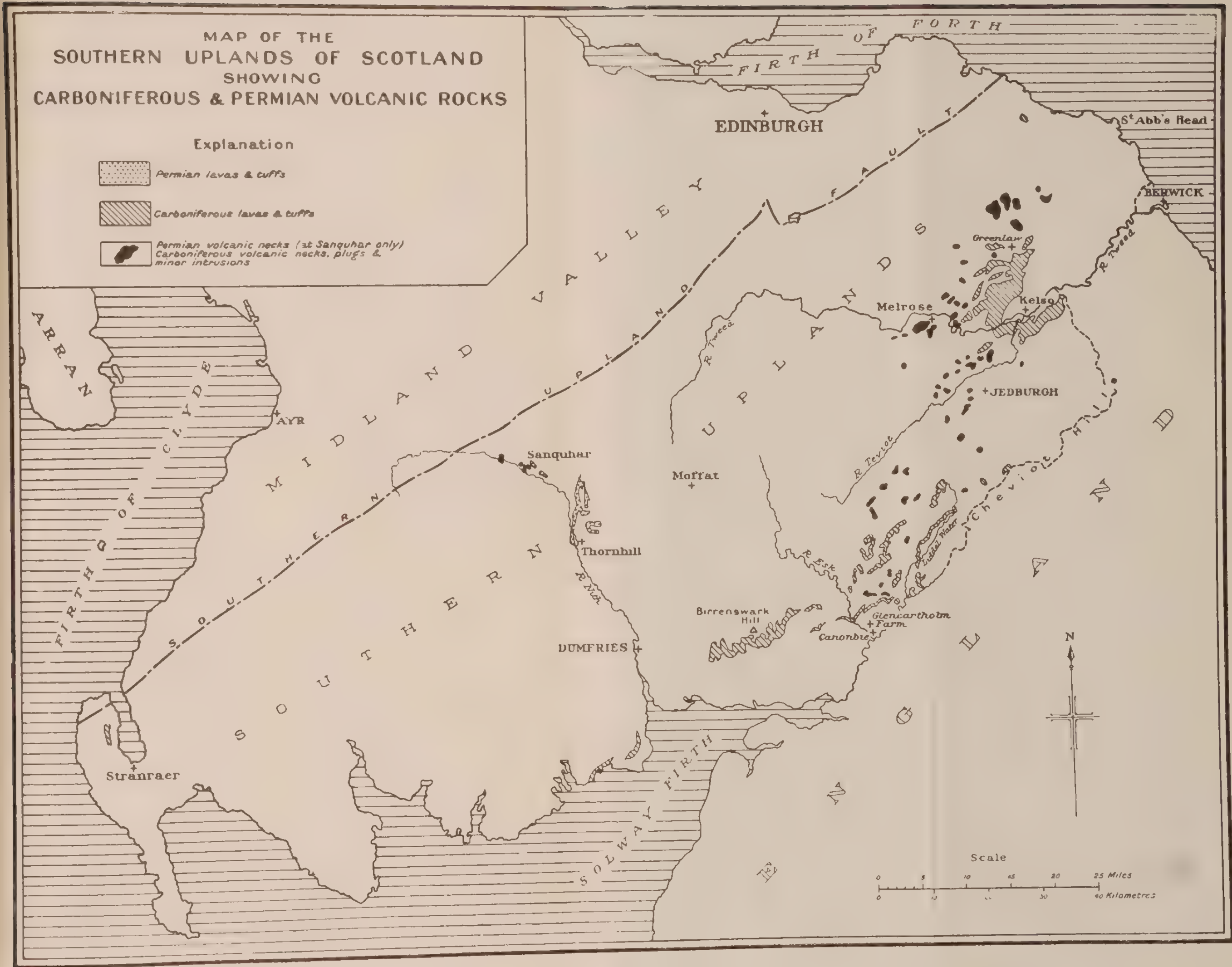
Fig. 1.

Fig. 2.



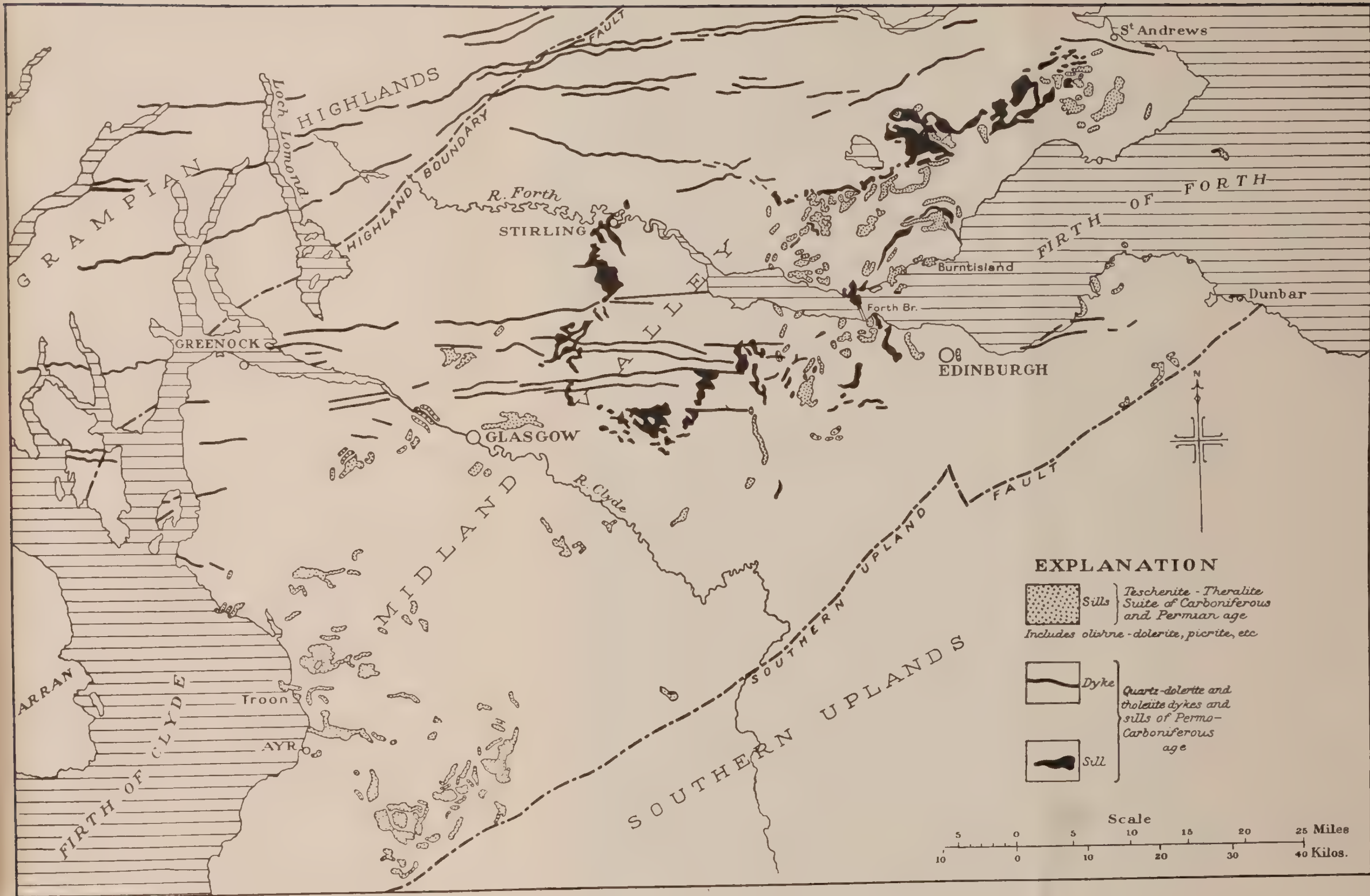
Map of the Midland Valley of Scotland, a rift valley ("graben") between the Highland Boundary and Southern Upland Faults, showing the distribution of Carboniferous and Permian lavas and volcanic necks.

Fig. 1.



MAP OF THE
SOUTHERN UPLANDS OF SCOTLAND
SHOWING
CARBONIFEROUS & PERMIAN VOLCANIC ROCKS
Explanation
Permian lavas & tuffs
Carboniferous lavas & tuffs
Permian volcanic necks (at Sanquhar only)
Carboniferous volcanic necks, plugs & minor intrusions
FIRTH OF FORTH
EDINBURGH
St Abb's Head
BERWICK
SOUTHERN UPLAND FAULT
MIDLAND VALLEY
SOUTHERN UPLANDS
ARRAN
FIRTH OF CLYDE
AYR
Greenlaw
Melrose
Kelso
JEDBURGH
R. Tweed
R. Teviot
Sanquhar
Moffat
Thornhill
R. Nith
R. Esk
Liddel Water
Cheviot Hills
Birrenswark Hill
Glencartholm Farm
Canonbie
DUMFRIES
Stranraer
SOLWAY FIRTH
ENGLAND
N
Scale
25 Miles
40 Kilometres

Fig. 2.



Map of the Midland Valley of Scotland and part of the Grampian Highlands, showing the distribution of the Late Carboniferous — Permian sills of teschenite etc., and sills and dykes of quartz — dolorite and tholeiite.

Fig. 3.

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Petrochemistry of the Scottish Carboniferous-Permian igneous rocks.

(With 12 Text-Figures)

CONTENTS

1. Introduction.

The original idea of the petrographical province (Judd, 1886) implies a certain unity of time, space and composition of the rocks under consideration. From this point of view the igneous rocks erupted during the Carboniferous and Permian periods in the area of the British Isles north of the Armorican mountain zone (Armorican foreland) belong to a definite petrographical, or igneous province.

Since Hutton's time the Midland Valley of Scotland, where the igneous rocks of this age are so abundantly and magnificently displayed, has been studied by a number of keen scientific workers. A certain amount of work has also been done on the very similar Carboniferous igneous rocks to be found in the Armorican foreland regions of England and Ireland. Chemical analyses of these rocks have been used in the present work to supplement those of the Scottish rocks.

This paper is an attempt to give a general account of the petrochemistry of the igneous rocks of the Midland

Valley of Scotland. It is mainly statistical, and incorporates all the available published and unpublished (by the present author) material. Although a preliminary account was given some years ago [1]), this work cannot be considered to be complete as yet. References to individual chemical analyses and petrographical descriptions of rocks cannot be given in this paper as they are far too numerous, but a general survey of the ground, descriptions of the leading rock-types and a bibliography will be found in a recently published summary of the geology of the Midland Valley of Scotland [2]).

2. The average chemical composition of rock-types.

There exist at the present time over 300 chemical analyses of the British Carboniferous-Permian igneous rocks of the Armorican foreland. Of these some 200 analyses were used in the present work, the remainder being either old incomplete analyses or analyses of contaminated or weathered rocks.

The basic unit taken is the rock-type as defined by its mineral composition Minor species and varieties determined by accessory minerals or by texture are included in the dominant rock-types. Modal analyses, either taken from published accounts or determined by the present author, were extensively used for the delimitation of rock-types. As this material is too voluminous to be given here, only a table showing the mineralogical-chemical correlation of the six classical types of olivine-basalt is given (Fig. 1). These six types differ mainly according to the relative proportions of feldspar and pyroxene and they are accordingly classed into three groups : pyroxene-rich (Hillhouse and

[1]) S. J. Tomkeieff. The British Carboniferous-Permian igneous province. Rep. Brit. Ass., Aberdeen, 1934, p. 312.

[2]) M. MacGregor and A. G. MacGregor. « British Regional Geology : The Midland Valley of Scotland ». Mem. Geol. Surv. Gt. Brit., 1936.

List of rock-types included in Tables I and II

1. Picrite (periodotite).
2. Picroteschenite (theralite, bekinkinite).
3. Teschenite (theralite, bekinkinite).
4. Lugarite.
5. Segregation vein in teschenite. F. Walker, Geol. Mag. 1926, p. 347.
6. Kylite. G. W. Tyrrell, Geol. Mag., 1912, p. 122.
7. Basanite (analcite-basalt, nepheline-basalt, monchiquite, limburgite).
8. Essexite (crinanite).
9. Analcite-syenite, segregation vein in essexite. G. W. Tyrrell, Geol. Mag., 1912, p. 72.
10. Olivine-basalt (Hillhouse & Craiglockhart types).
11. Olivine-basalt (Dalmeny & Dunsapie types).
12. Olivine-basalt (Jedburgh & Markle types).
13. Olivine-basalt (six types).
14. Mugearite (trachybasalt).
15. Trachyandesite.
16. Phonolite (phonolitic trachyte).
17. Trachyte (orthophyre, bostonite, keratophyre, quartz-banakite).
19. Rhyolite (felsite).
19. Olivine-dolerite.
20. Quartz-dolerite.
21. Segregation veins in quartz-dolerite (intermediate).
22. Segregation veins in quartz-dolerite (acid).

Average composition of rock-types (FeS_2 includes also S an
in the averages for lac

No.	1	2	3	4	5	6	7	8	9	10
Number of analyses averaged	4	7	22	2	1	1	17	9	1	8
SiO_2	40,74	43,80	45,67	46,40	55,27	44,18	43,14	46,42	56,44	44,41
TiO_2	1,31	1,83	2,39	1,45	0,80	1,30	2,31	2,03	1,16	2,61
Al_2O_3 . . .	7,11	10,92	15,39	16,35	17,86	10,67	14,44	15,28	15,54	13,93
Fe_2O_3 . . .	3,51	4,07	3,39	4,91	1,95	0,97	3,77	2,28	3,27	3,15
FeO	10,18	8,14	7,14	5,88	4,91	10,03	7,78	8,69	3,67	8,85
MnO . . .	0,23	0,24	0,20	0,14	tr.	—	0,21	0,25	—	0,19
MgO . . .	23,22	13,50	5,66	2,20	2,34	17,77	9,86	6,49	1,73	9,43
CaO	5,32	7,92	8,09	5,29	4,08	9,75	10,20	9,55	4,16	9,79
Na_2O . . .	1,58	2,73	3,82	8,81	5,24	2,37	2,91	3,96	5,81	2,89
K_2O	0,58	1,04	2,19	1,58	3,39	1,23	1,45	1,78	4,27	1,36
P_2O_5 . . .	0,26	0,39	0,59	0,87	0,27	0,38	0,64	0,56	0,83	0,52
FeS_2	0,09	0,17	0,20	—	0,06	—	0,06	0,11	—	0,18
CO_2	0,08	0,05	1,18	—	abs.	tr.	0,20	0,16	0,97	0,07
$+ H_2O$ . . .	5,21	3,63	3,65	4,82	3,15	0,97	2,68	2,09	2,06	2,32
$— H_2O$ . . .	0,58	1,57	0,44	1,30	0,80		0,35	0,35	0,44	0,30
Total	100,00	100,00	100,00	100,00	100,12	99,62	100,00	100,00	100,35	100,00
Average specific gravity. . .	2.919	—	2.788	—	—	—	2.899	—	—	—

TABLE I

O3, other minor constituents have not been included
f the necessary data)

11	12	13	14	15	16	17	18	19	20	21	22
8	11	27	10	10	9	14	4	12	38	4	6
45,61	46,29	45,55	50,39	56,68	57,76	61,67	72,56	47,46	50,05	61,07	70,30
2,28	3,23	2,76	2,29	1,56	0,41	0,59	0,18	2,26	2,50	1,69	0,41
14,75	16,62	15,26	16,12	17,08	18,45	15,82	12,96	14,78	14,48	13,71	12,33
4,86	3,83	3,94	6,11	3,99	2,78	3,76	1,78	3,02	3,28	2,39	1,21
7,62	7,88	8,09	5,11	3,02	3,11	2,31	1,11	8,01	9,05	5,14	2,71
0,18	0,22	0,20	0,23	0,35	0,17	0,22	0,08	0,16	0,12	0,12	0,02
7,74	5,24	7,22	3,41	2,12	0,60	0,95	0,65	7,28	4,84	1,79	0,83
8,58	8,93	9,10	4,77	3,83	1,91	2,04	0,68	8,46	8,69	3,46	2,16
2,72	3,34	3,01	4,21	5,11	6,46	5,30	2,98	3,03	2,46	4,64	3,97
1,22	1,24	1,27	2,79	3,40	5,96	4,55	4,53	1,13	1,14	2,20	3,07
0,37	0,45	0,45	0,46	0,33	0,19	0,16	0,06	0,36	0,35	0,39	0,21
0,06	0,05	0,09	0,10	0,01	0,19	0,08	0,06	0,09	0,22	0,55	0,20
0,39	0,16	0,20	0,95	0,06	0,08	0,70	0,36	0,48	0,35	0,24	0,80
2,48	1,75	2,11	2,46	1,58	1,68	1,14	1,63	2,62	1,94	1,70	1,56
1,14	0,77	0,75	0,60	0,88	0,25	0,71	0,38	0,86	0,53	0,91	0,22
100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00
—	—	2.847	2.694	—	2.596	2.545	2.424	2.854	2.935	2.662	2.590

NIGGLI values g

No.	1	2	3	4	5	6	7	8	9	10	11
si	70,50	90,40	114,20	126,00	177,40	80,25	91,10	107,10	187,50	95,90	106,00
qz	— 42,70	— 37,00	— 36,80	— 77,60	— 15,40	— 42,15	— 40,50	— 38,90	— 22,60	— 35,70	— 25,80
al	7,25	13,30	22,70	26,20	33,70	10,80	18,00	20,90	30,50	17,70	20,20
fm	79,55	62,30	42,85	32,60	29,05	64,60	51,10	43,75	26,95	51,75	50,45
c	9,90	17,55	21,70	15,30	14,05	19,00	23,00	23,85	14,80	22,65	21,40
alk	3,30	6,85	12,75	25,90	23,20	5,60	7,90	11,50	27,75	7,90	7,95
aa	0,45	0,51	0,56	0,99	0,69	0,52	0,44	0,55	0,91	0,45	0,39
mg	0,75	0,67	0,49	0,27	0,38	0,74	0,61	0,52	0,32	0,59	0,53
c/fm	0,12	0,28	0,51	0,47	0,48	0,29	0,45	0,55	0,55	0,44	0,44
k	0,20	0,20	0,27	0,11	0,30	0,26	0,25	0,23	0,33	0,24	0,23
ti	1,71	2,80	4,50	2,95	1,93	1,78	3,65	3,50	2,90	4,23	3,98
p	0,19	0,35	0,63	0,99	0,37	0,29	0,58	0,54	1,16	0,51	0,36
co_2	0,19	0,14	4,00	—	—	—	0,58	0,50	4,42	0,21	1,24
h_2o	33,40	35,85	34,10	55,40	42,25	5,85	21,30	18,80	27,70	19,10	28,05

TABLE II

k-type averages

12	13	14	15	16	17	18	19	20	21	22
13,20	105,60	145,30	187,30	201,20	238,00	415,50	113,20	130,80	230,00	353,30
26,20	— 29,00	— 22,30	— 6,70	— 38,80	+ 14,00	+ 183,10	— 22,20	— 1,60	+ 45,00	+ 136,00
24,00	20,85	27,45	33,25	37,90	36,00	43,75	21,00	22,30	30,40	36,70
42,75	47,90	40,85	29,75	19,95	24,55	18,95	48,25	45 30	33,40	22,35
23,40	22,60	14,80	13,50	7,15	8,45	4,20	21,90	24,30	13,95	11,65
9,85	8,65	16,90	23,50	35,00	31.00	33,10	8,85	8,10	22,25	29,30
0,41	0,42	0,62	0,71	0,93	0,86	0,76	0,42	0,36	0,73	0.80
0,45	0,52	0,36	0,35	0,16	0,22	0,29	0,54	0,41	0,30	0,28
0,55	0,47	0,36	0,46	0,36	0,34	0,22	0,45	0,54	0,42	0,52
0,20	0,22	0,31	0,30	0,38	0,36	0,50	0,20	0,23	0,25	0,34
5,95	4,80	4,98	3,87	1,07	1,71	0,79	4,10	4,90	4,80	1,54
0,47	0,45	0,56	0,46	0,27	0,26	0,14	0,36	0,39	0,63	0,45
0,53	0,64	3,85	0,28	0,39	3,69	2,82	1,58	1,25	1,25	5,50
20,60	22,10	29,50	27,10	22,45	23,80	38,80	26,60	21,50	32,80	30,00

Craiglockhart types), intermediate (Dalmeny and Dunsapie types), and feldspar-rich (Jedburgh and Markle types). The average chemical composition of these groups will be found in Table I (nos. 10, 11, 12).

The same method has been applied to the other rock-types, the corresponding analyses averaged (Table I), and the corresponding Niggli values calculated (Table II). In

CARBONIFEROUS OLIVINE-BASALTS.				
	PYROXENE-RICH		FELDSPAR-RICH	TEXTURE
MACRO-PORPHYRITIC	Craiglockhart Type	Dunsapie Type	Markle Type	INTER-GRANULAR
MICRO-PORPHYRITIC	Hillhouse Type	Dalmeny Type	Jedburgh Type	OPHITIC
SiO_2 AVERAGE	44·41	45·61	46·29	
SiO_2 RANGE	42·49 – 46·58	44·65 – 46·96	44·50 – 47·71	
1 RANGE	24 – 49	34 – 74	62 – 80	
PHENO-CRYSTS	Pyroxene	Feldspar / Olivine	Feldspar	

$$1 = \frac{\text{F-rs} + \text{F-oids}}{(\text{F-rs} + \text{F-oids}) + (\text{Pyr} + \text{Chl.})} \times 100$$

Fig. 1. — Classification of Carboniferous olivine-basalts.

the list of rock-types the names in brackets indicate subsidiary types or alternate names of rocks included in the main type. The number of analyses entering into a single average is extremely variable and in certain cases important types have had to be represented by a single analysis (nos 5, 6, 9). The averages for the specific gravity were obtained from from 377 individual determinations. Among the Niggli values the value aa = alk/al is introduced. It is useful for the determination of the degree of under- or over-saturation (anorthite aa = 0, si = 100, albite aa = 1.00, si = 300).

3. The principal rock-series.

In order to obtain a greater degree of precision, the term *series* is used to signify a genetic lineage of rocks, while the term *suite* is reserved for the formal classification according to the relative proportion of alkalies. Series, in general, may or may not fall into suites. In our case each of the principal series falls almost entirely into a specific suite. The series are called after their dominant member, altough they may vary greatly in their range.

The three principal series are as follows :

	Series	Dominant suite	Dominant age
I.	Olivine-basalt	Alkalic	Early Carboniferous
II.	Teschenite	Per-alkalic	Late-Carboniferous - Early-Permian
III.	Quartz-dolerite	Calc-alkalic	Early Permian

As all series cut across the isochronic lines, their age, like their suites, can only be stated as dominant. Usually the end of one series overlaps with the beginning of another.

The approximate classification of the rock-types of the series is shown on the alkali-silica diagram (Fig. 2). To save space the silica scale is logarithmic. The members of each series are connected by straight lines showing their genetic connections. The curve with an arrow-point indicates the composition of the segregation veins of quartz dolerite.

The first series ranges from olivine-basalt to rhyolite and has a phonolite branch. It includes not only the lavas but also the intrusions of analogous rock-types, which, there are reasons to suppose, are pene-contemporaneous with the lavas. The second and the third series are entirely intrusive in character.

There are, however, two minor series not shown on the diagram. As they are closely connected with the first series they may be called co-lateral series, and, on the other hand, as they form links between the principal series they may also be called transition series. They are the essexite

series (kylite, basanite, crinanite, essexite and segregation veins of analcite-syenite), and the olivine-dolerite series. Basanite (including monchiquite, limburgite, etc.) is a difficult

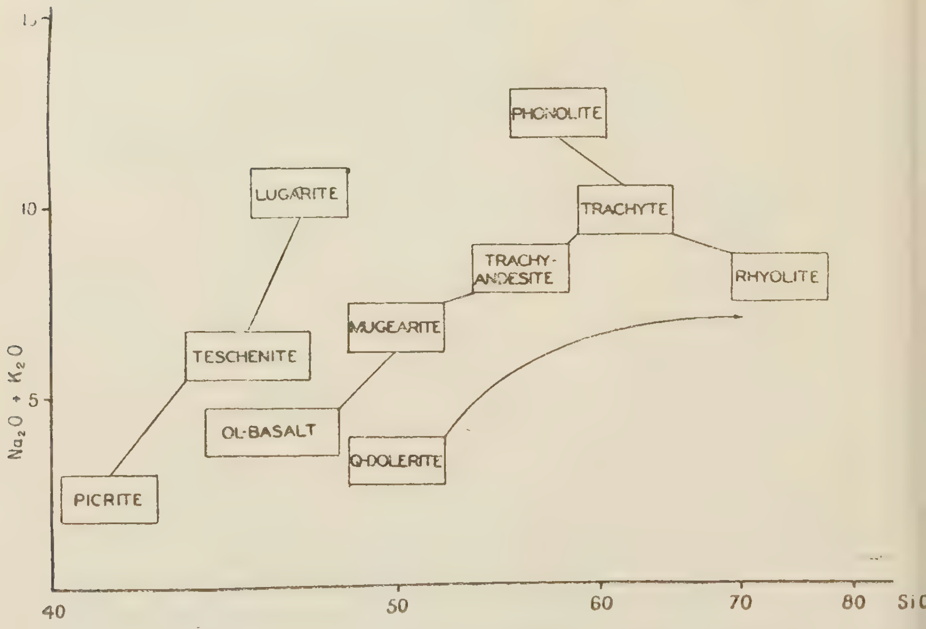

Fig. 2. — Classification of Carboniferous igneous rocks on alkali-silica diagram.

type to place, as some basanites occur as lavas of the first series while others may really belong to the second series.

4. The relative amounts of rock-types.

A rough planimetric estimate of the size of the areas at present occupied by various rock-types in the Midland Valley of Scotland gives the following approximate results:

Lavas	. . . .	75.0	per cent
Intrusions	Olivine-dolerite and essexite .	7.5	»
	Quartz-dolerite . . .	7.5	»
	Teschenite	7.5	»
	Varia . . . . . ,	2.5	»

The lavas can be assigned to six distinct regions (plateaux) :

1) Clyde (Campsie, Kilpatrick and Renfrewshire Hills, Arran, Kintyre, Antrim).— Lower Calciferous Sandstone age.
2) Lothian (Garleton Hills, Arthur's Seat, etc.).— Lower Calciferous Sandstone age.
3) Fife (Burntisland district), — Upper Calcif. Sandstone age.
4) Bathgate (Linlithgow, Saline Hills, etc. — Upper Calciferous Sandstone to Upper Carboniferous Lst. age.
5) Ayrshire (Arran, Kintyre). — Millstone Grit age.
6) Mauchline (Ayrshire). — Permian age.

The original volume of the lavas erupted can only be arrived at by a number of assumptions and the results are therefore extremely approximate (Table III). The area formerly covered by lavas (for each region) is estimated by the known extent of the occurrence of these lavas. The areas thus obtained are then converted to circular areas of radius r. Assuming that the lavas are thinning out in all directions from the centre, the volume of the lava is that of a spherical segment of radius r and height h (maximum thickness of lava). This volume is

$$V = \frac{1}{6} \pi h (h^2 + 3 r^2)$$

The relative abundance of various rock-types in each region can be calculated by taking the relative proportions of types in vertical sections weighed by their probable lateral extent. The results of these calculations for the whole of the Midland Valley of Scotland (six regions) is given in Table IV.

From the relative abundance of types and their average chemical composition, the composition of the average lava can easily be calculated (Table V).

The relative amounts of different lava-types plotted against silica give a characteristic frequency distribution curve with a mode corresponding to $SiO_2 = 46{,}80$ (Fig. 3).

TABLE III

Volume of plateau lavas erupted in different regions of the Midland Valley of Scotland

Region No.	Radius (r) of the area (miles)	Area (miles) 2	Maximum thickness (feet)	Volume of lavas (miles) 3	Volume of lavas (per cent.)
1	40	5025	2000	1275	86,60
2	15	705	1000	70	4,75
3	5	80	1000	8	0,55
4	10	315	1500	44	3,00
5	20	1255	500	60	4,10
6	10	315	500	15	1,00

TABLE IV

Relative amounts of rock-types erupted in the Midland Valley of Scotland

	Rock - type	Volume (per cent.)	Density	Weight (per cent.)	
	Rhyolite	0,97	2,42	0,84	
	Trachyte	3,41	2,54	3,09	
	Trachyandesite	3,13	2,60	2,90	
	Mugearite	12,32	2,69	11,80	
Ol. Basalt	Jedburgh T.	30,33	2,89	31,17	79,92
	Markle T.	28,00	2,85	28,37	
	Dalmeny T.	13,92	2,75	13,65	
	Dunsapie T.	3,06	2,85	3,11	
	Hillhouse T.	1,89	2,92	1,97	
	Craiglockhart T.	1,57	2,94	1,65	
	Basanite	1,40	2,90	1,45	

TABLE V

Calculated composition of the average lava

SiO_2	47,59
TiO_2	2,75
Al_2O_3	16,04
Fe_2O_3	4,20
FeO	7,12
MnO	0,21
MgO	5,45
CaO	8,05
Na_2O	3,40
K_2O	1,63
P_2O_5	0,43
FeS_2	0,07
CO_2	0,32
$+ H_2O$	1,94
$- H_2O$	0,80
	100,00

si = 119,60
qz = — 24,00

al	= 23,75	aa	= 0,46
fm	= 43,70	mg	= 0,47
c	= 21,65	c/fm	= 0,50
alk	= 10,90	k	= 0,24

ti = 5,20
p = 0,45
co_2 = 1,10
h_2o = 22,95

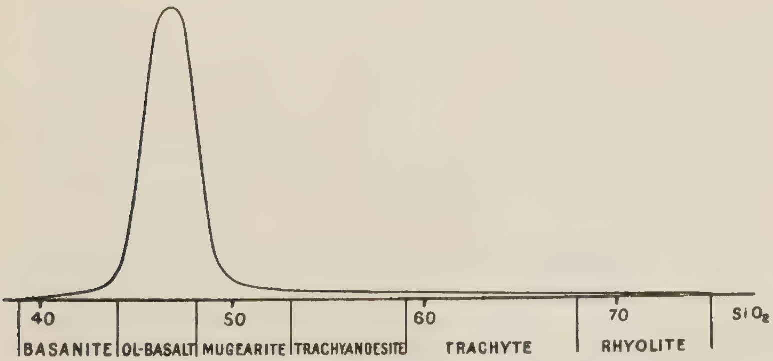

Fig. 3. — Frequency distribution curve of the lava-types.

It is constructed by taking the area enclosed between the curve and the cut of the abscissa corresponding to the

silica range of a given type, to be proportional to the relative abundance of this type. The curve is markedly assymetric. It has a relatively larger proportion of types with a higher silica content, or, what amounts to the same, a deficiency in the basic or ultrabasic regions. This fact finds its expression in the difference between the silica percentage of the calculated average lava ($SiO_2 = 47.59$) and that of the mode ($SiO_2 = 46.80$). The significance of this will be discussed later.

It is impossible to deal in the same way with the other series. The teschenite series, ranging from picrite to alkaline segregation veins, is mainly determined by gravitational differentiation (sinking of olivine) and the amount of ultrabasic and alkaline differentiate probably does not exceed ten per cent. The frequency distribution curve in this case must therefore fall off rapidly away from the mode (teschenite) in both directions. The bulk of the quart-dolerite series consists of quartz-dolerite, as the amount of the intermediate and acid differentiate (segregation veins and patches) is negligible.

5. Comparative study of rock-types and series.

One of the methods of tracing the relations between individual members of one genetic series, consists in the construction of variation diagrams. Such diagrams are customarily constructed from individual analyses. This was the procedure at first adopted in the present work, but the multitude of individual points and their wide dispersion made the resulting diagrams unsuitable for presentation as very confusing. The conversion of individual points to average points brings out much more clearly the relations between the rock-types, although in the process certain details are inevitably lost (compare Figs 11 and 12). According to the theory of probability the observational error decreases with the increase of the number of data recorded. In the application of this idea in petrochemistry very great care must be exercised in the selection of the individual

analyses entering into an average and the correlation of rock-types averaged must always be carefully checked by the distribution-trends of the individual analyses. Thus the lines connecting the average points must follow the trend of individual points.

Of all the diagrams, the most instructive is that showing the variation of the total alkalies against silica (Fig. 4). In this diagram, as well as in those which follow, the members of each series are represented by a special sign : te-

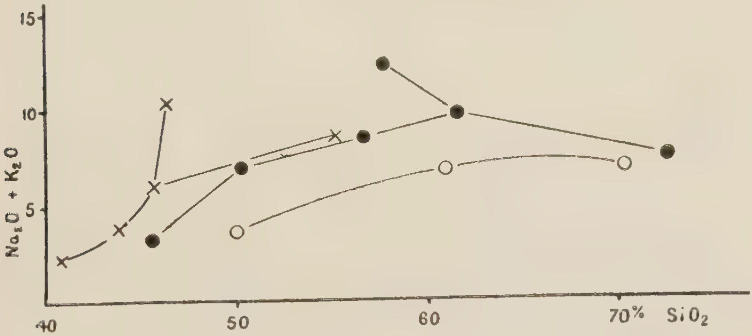

Fig. 4. — The principal series on the alkali-silica diagram.

schenite—cross, olivine basalt—filled circle, quartz dolerite—open circle. The series of essexite (inverted triangle) and olivine dolerite (triangle) are omitted from the series variation diagrams, as they run very close to the principal series and would obstruct the representation. In the alkali-silica diagram (Fig. 4) the principal series appear quite isolated from each other, but actually their fields are overlapping. In would be more correct, therefore, to represent each series by a band, but this would certainly obscure the representation. For the same reason the names of rock-types are omitted from these diagrams, but they can easily be found by referring to Fig. 2 or Tables I and II.

The alkali-silica diagram (Fig. 4) should be compared with the density-silica diagram (Fig. 5) and the von Wolff diagram, constructed for the same rock-series (Fig. 6). Some of the rock-types are not given on the density-silica diagram, but in spite of this the general similarity to the

alkali-silica diagram is most striking. The difference between the von Wolff diagram and the other two lies in the fact that in the von Wolff diagram olivine basalt is represented by three points (corresponding to three main groups) while

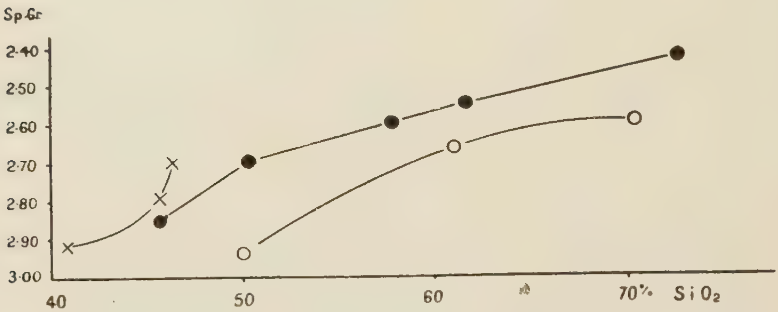

Fig. 5. — The principal series on the density-silica diagram.

in the other two diagrams only the average olivine basalt is given. The von Wolff diagram as represented in Fig. 6 is

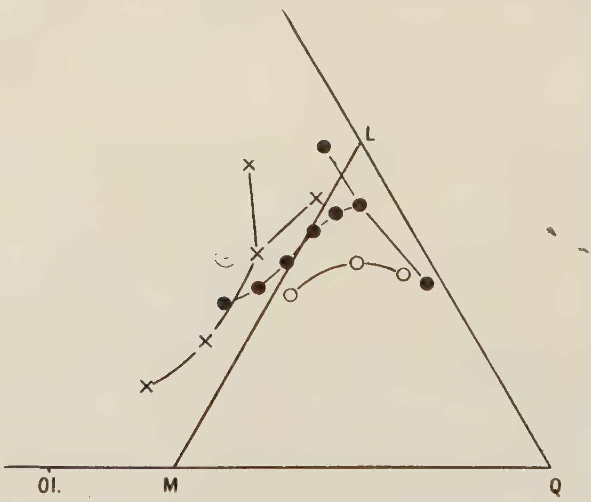

Fig. 6. — The principal series on the von Wolff diagram.

purposely turned round in order to facilitate comparison. Allowing for a certain amount of distortion necessitated by the method of projection, the von Wolff diagram is on the whole very similar to the alkali-silica diagram, and

this shows that, for the purpose of comparison of analyses, the von Wolff method can be effectively replaced by a simple plotting of the alkalies against silica.

By the use of Niggli values we can attain some further simplifications. This can be clearly seen in comparing Fig. 4 with Fig. 7. And so for the remaining variation diagrams the Niggli values are used. One must remember, however, that *si* is calculated only in relation to *al*, *fm*, c and *alk*, so that the influence of H_2O and other volatiles cannot be seen in these diagrams. This applies especially to the teschenite series, which would be much more separated from the olivine-basalt series if H_2O and CO_2 were taken into account (See Table II). In all these diagrams *si* is plotted on a logarithmic scale in order to bring them into line with the ordinary variation diagrams. The diagrams for *alk* (Fig. 7), *al* (Fig. 8), *c* (Fig. 9) and *fm* (Fig. 10) are so arranged as to show vertically the sympathetic variation and horizontally antipathetic and reverse variations.

The variations of other Niggli values (Table II) are not illustrated by diagrams. Their general trend for all series is as follows : with the increase of *si*, *k* and *aa* rises, *mg* falls, *c/fm* first rises then falls. The relation between *mg* and *k* can be expressed by an approximate formula :

$$mg = 1.30 - 3.25\ k$$

The only wide divergence from this formula occurs with lugarite and rhyolite and it shows that lugarite is abnormally enriched in soda and rhyolite in potash.

No further explanation is needed as the major facts can be derived from the study of the diagrams themselves while the minor facts are not discussed in this paper.

6. The problem of differentiation.

The prevalence of olivine basalt among the Scottish Carboniferous-Permian igneous rocks and the nature of the frequency distribution curve of the lava series suggest that

we are dealing with comagmatic series and that olivine basalt represents the primary magma. A consideration of the

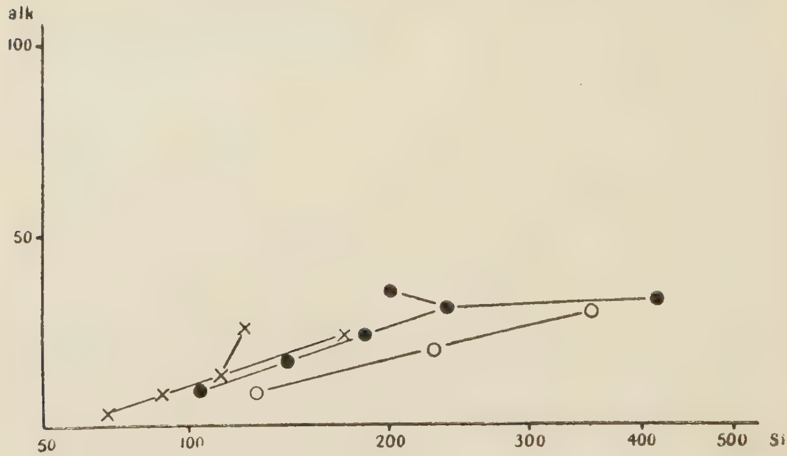

Fig. 7. — The principal series on the *alk-si* diagram.

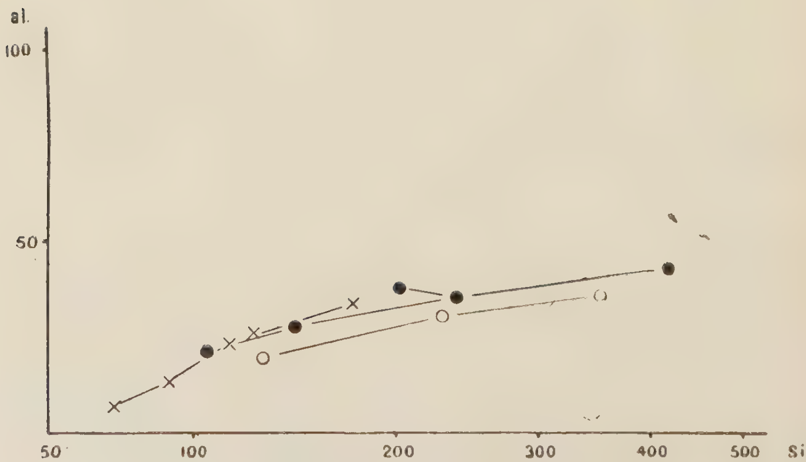

Fig. 8. — The principal series on the *al-si* diagram.

eruptive chronology combined with that of the variation diagrams may help us to solve the problem of the origin of the various rock-types.

The main sequence of the series is that shown on p. 67, but the series certainly overlap in time, so, that, in all

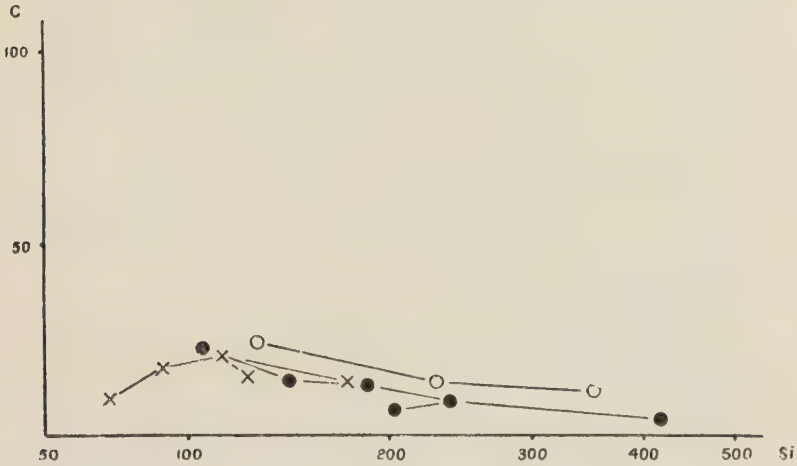

Fig. 9. — The principal series on the *c-si* dîagram.

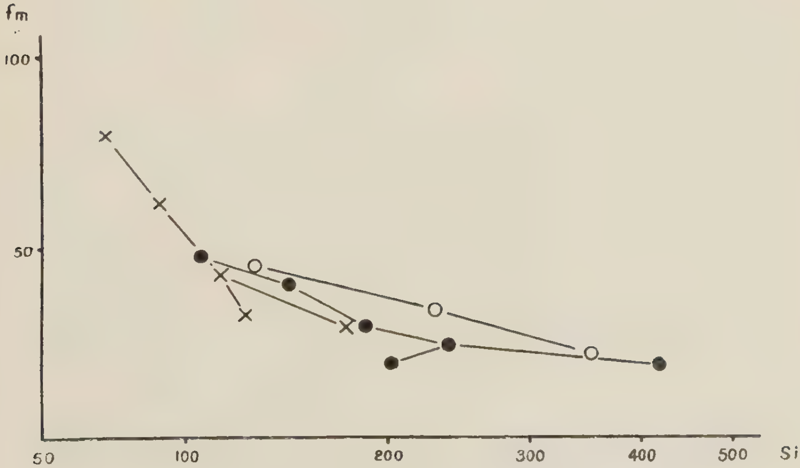

Fig. 10. — The principal series on the *fm-si* diagram.

probability, the intrusions of the teschenite series began before the termination of the volcanic phase of the first series.

The sequence of types within the volcanic phase of the first series is not clearly defined. On the whole the lower lava complexes (Clyde and Lothian) display a wide range of types (from olivine basalt to rhyolite), while the higher lava complexes consist mainly of olivine-basalt which in the Permian is more alkaline and in this respect approaches the teschenite series. Although the sequence of the individual lava flows among the lower lavas is somewhat capricious, one is tempted to distinguish the following eruptive cycle : olivine-basalt - mugearite - trachyte - rhyolite, which is, in certain regions, recurrent.

The pene-contemporaneous intrusions are, on the whole, analogous to the lavas, but basanite, essexite, olivine-dolerite and phonolite are probably of a slightly later date.

The continuous variation shown by all the members of the first series and the nature of the frequency distribution curve suggest that all the types originated from the parent olivine-basalt magma. The assymetry of the curve suggests also the presence of an unaccounted for amount of basic or ultrabasic material — perhaps a product of gravitational differentiation — which was never erupted and which solidified under plutonic conditions. It may be represented by the isolated fragments which, in the form of peridotite inclusions, are frequently fond in the intrusive basanites [1]).

If this explanation be accepted, the hidden ultrabasic portion of the magma will redress the balance of the frequency distribution curve (Fig. 3). Using the terminology proposed by Scheumann [2]) the portion of the curve situated to the left of the modal peak will thus represent the accumulative phase of the magma. that to the right-its fusive phase.

But are we justified in explaining the whole series as a product of gravitational differentiation ?

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[1]) S. I. Tomkeieff. The volcanic complex of Calton Hill (Derbyshire). Quart. Journ. Geol. Soc. London, vol. 84, 1928, p. 703.

[2]) K. H. Scheumann. Zur Genese alkalisch-lamprophyrischer Ganggesteine. Centrbl., f. Min., etc., 1922, p. 495.

A rough estimate (Table VI) of the material subtracted from one rock-type to produce another, and recalculated only for the principal constituents and mainly in terms of olivine and feldspar, clearly demonstrates the difficulties encountered by the gravitational differentiation hypothesis. Certainly, this calculation shows an extreme case and takes no account of the possibility of addition of material (flotation of crystals, diffusion, etc.). Even so, it is difficult to imagine the fusive phase extending beyond mugearite supposing the differentiation to be exclusively determined by the sinking of olivine. From Table VI the impression is gained, that, on the whole, the series is determined by progressive crystallization of feldspar, but one must not forget the control exercised by pyroxene which was not fully accounted for in the estimate. Another interesting feature of this table is that the progressively diminishing amounts of the liquid fraction are somewhat analogous to the frequency distribution of the actual rock-types corresponding to these liquids (Table IV).

This rejection of gravitational differentiation as the sole explanation of the whole series leaves the following three points for consideration :

1) The gravitational differentiation (sinking of olivine) may account for the accumulative ultrabasic phase of the series and its corresponding fusive phase extending in the direction of mugearite.

2) The main trend of the series, however, is better explained by crystal fractionation, without going into precise details as to the actual mechanism of separation of the liquid from the solid phase.

3) The bifurcation of the main series line into phonolite and rhyolite branches must involve some other processes of differentiation which will be discussed at a later stage of this paper.

The last point is closely bound up with the question of the origin of the three principal series. These three series are represented by their dominant rock-types : — teschenite, olivine-basalt and quartz-dolerite. Olivine-basalt,

TABLE VI

Calculation of the amount and composition of the material required to be subtracted from one rock-type to produce another

MATERIAL SUBTRACTED		COMPOSITION OF THE MATERIAL SUBTRACTED				Amount of material subtracted	Amount of residual liquid
FROM	TO PRODUCE	OLIVINE	Iron ore	$CaSiO_3$	FELDSPAR		
Ol. basalt . . .	Mugearite . . .	19,90 (fa_{45} fo_{55})	3,80	6,60	22,50 (an_{75} ab_{25} or_0)	52,80	47,20
Mugearite . . .	Trachyandesite .	4,25 (fa_{53} fo_{47})	4,30	0,80	14,25 (an_{34} ab_{48} or_{18})	23,60	23,60
Trachyandesite . .	Trachyte . . .	1,25 (fa_{58} fo_{42})	1,25	0,20	9,10 (an_{30} ab_{54} or_{16})	11,80	11,80
Trachyte . . .	Rhyolite. . . .	—	1,10	0,55	6,65 (an_6 ab_{62} or_{32})	8,30	3.50

by far the most abundant of the three, may be taken as corresponding to the primary magma, the other two representing the derivative magmas. What then are the relations between these magmas ?

By plotting all the individual analyses on the alkali-silica diagram (Fig. 11) we see a close interpenetration of the fields occupied by the various rock-types and an unin-

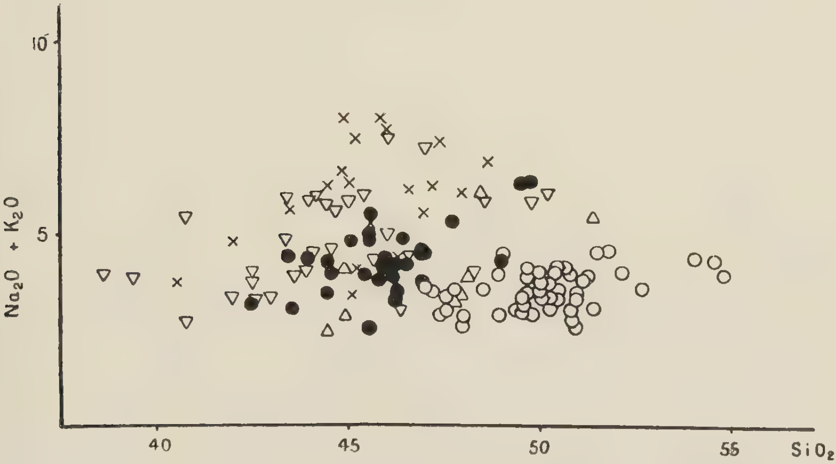

Fig. 11. — The individual points for teschenite × essexite and basanite ▽ olivine-basalt ● olivine-dolerite △ and quartz-dolerite ○ on the alkali-silica diagram.

terrupted succession from teschenite to quartz-dolerite. A more illuminating diagram (Fig. 12) is obtained by converting individual points to average points and representing the trends of the series by straight lines.

From top to bottom the series appear in the following order : - (1) teschenite, (2) essexite, (3) olivine basalt (the point represented on the diagram corresponds to the average lava and not to the average basalt), (4) olivine-dolerite, (5) quartz-dolerite.

The petrographic evidence shows that these types are linked up by transitional types, and even quartz-dolerite displays varieties in which olivine is present.

The extreme members of this « transverse » series are teschenite and quartz-dolerite and calculation shows that a mixture of these two types in 1 : 1 proportion is not unlike the average lava (Table VII), the only two important differences referring to $Al_2 O_3$ and CO_2.

The variation of these three types is better shown by the NIGGLI values (Table VIII), The major compo-

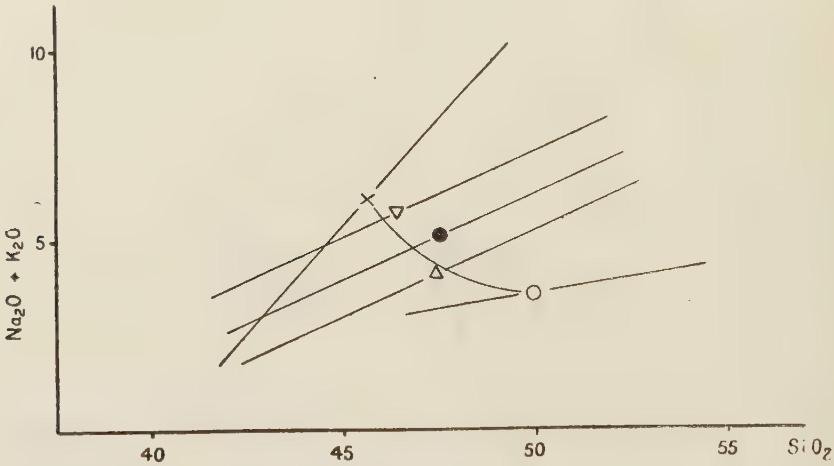

Fig. 12. — The average points for the rocks represented on Fig. 11 on the alkali-silica diagram.

nents of these types can be divided into two antipathetically varying groups :

$$A. \ (alk, \ al) + (p, \ co_2, \ h_2o)$$
$$B. \ (c, \ fm)$$

The differentiation could be accounted for either by the differential movement of groups A or B, ore both A and B. The differential movement of B could de explained by the gravitational separation of olivine and basic feldspar, but this process would result in the lowering of *si*, which is not the case. This, as well as the petrographic evidence, precludes the possibility of quartz-dolerite being the accumulative phase of olivine-basalt magma. The se-

cond alternative — the differential movement of group A (mainly alkalies and volatiles) — is much more plausible. This would mean that the volatile (hyperfusible) constituents of the primary magma, together with the alkalies, can gradually diffuse through the body of the liquid magma and concentrate in the upper part of the magma reservoir. Given enough time the primary magma would thus divide into two conjugate magma portions, the upper — teschenitic and the lower, quartz-doleritic. The composition of these conjugate magmas can therefore be expressed as follows : —

Teschenite magma = primary magma + alkalies and volatiles.

Quartz-dolerite magma = primary magma — alkalies and volatiles.

TABLE VII

Comparison of the average lava and the mixture of teschenite and quartz-dolorite in 1 : 1 proportion

	1.	2.
SiO_2	47,59	47,86
TiO_2	2,75	2,44
Al_2O_3	16,04	14,94
Fe_2O_3	4,20	3,33
FeO	7,12	8,10
MnO	0,21	0,16
MgO	5,45	5,25
CaO	8.05	8,39
Na_2O	3,40	3,14
K_2O	1,63	1,66
P_2O_5	0,43	0,47
FeS_2	0,07	0,21
CO_2	0,32	0,77
$+ H_2O$	1,94	2,80
$— H_2O$	0,80	0,48
	100,00	100,00

1. Average lava.
2. Mixture of teschenite and quartz-dolorite in 1 : 1 proportion.

TABLE VIII

Comparison of Niggli values for teschenite, average lava, and quartz-dolorite

	Teschenite		Average lava		Quartz-dolerite	
si	114,20		119,60		130,80	
alk	12,75	35,45	10,90	34,65	8,10	30,40
al	22,70		23,75		22,30	
c	21,70	64,55	21,65	65,35	24,30	69,60
fm	42,85		43,70		45,30	
p	0,63		0,45		0,39	
co_2	4,00	38,73	1,10	24,50	1,25	23,14
h_2o	34,10		22,95		21,50	

The alkali-volatiles diffusion as a factor of differentiation was suggested by C. H. Smyth [1]) and subsequently emphasised by Niggli, Fenner and Gillson. The process of diffusion, however, must not be confused with the process of gas transfer (two-phase transfer). The differential lowering of pressure in a magma reservoir may lead to a diffusion of the lighter, volatile-rich, magmatic fraction through the body of the magma, without actual separation of the gas phase (ebullition). It is probable that only in an open vent system can a stream of gas bubble be produced. Again, although, the diffusion will result in the formation of two liquid fractions, these fractions will not constitute immiscible liquids and will grade into one another. The alkali-volatile diffusion must be a very slow process and depend not only on time but also on the differential pressure in the magma reservoir. Fractions thus

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1) C. H. Smyth, Jr. The chemical composition of the alkaline rocks and its significance as to their origin. American Journ. Science, vol. 36, (4th ser.), 1913, p. 33.

separated could, say during a subsequent movement of the magma, be brought into close contact without having time to mix before their consolidation. This idea has already been expressed by the present author in his study of the dolerite-pegmatite schlieren of quartz-dolerite sills [1]).

The curve connecting teschenite and quartz-dolerite (Fig. 12) indicates the trend of this differentiation. It has purposely beem drawn through a point on the olivine-basalt line corresponding to the silica of the modal peak of the frequency distribution curve (Fig. 3) and not through the average point of the olivine-basalt series. This curve passes quite close to the essexite and the olivine-dolerite points, so that these rocks can be included in the « transverse » series. It serves to emphasise yet once more that essexite and olivine-dolerite should be regarded as the first stages of diffusion-differentiation of primary magma, - the first conjugate magmas. At a later date the primary magma differentiated more intensely into teschenite and quartz-dolerite magmas.

The concentration of volatiles in the upper zone of the magmatic reservoir apparently lowered the viscosity of the corresponding magma, and in this way facilitated the gravitational separation of olivine. The effects of this separation, either slightly before or immediately after the actual emplacement of the magma, are very marked in the teschenite series (peridotite-picrite-teschenite) and also in the essexite series. This was shown by Tyrrell [2]) in whose nomenclature it appears as the « crinanite » series. No effects have as yet been observed in the olivine-dolerite series and they are completely absent in quartz-dolerite. It is possible therefore to correlate the intensity of the gravitational differentiation with the alkali-volatile content of the magma, and the inclination of the lines-series (Fig. 12)

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1) S. I. Tomkeieff. A contribution to the petrology of the Whin Sill. Mineralog. Mag., vol. 22, 1929, p. 100.

2) G. W. Tyrrell. Classification and age of the analcite-bearing igneous rocks of Scotland. Geol. Mag., vol. 60, 1923, p. 249.

may serve as a rough index of the intensity of this differentiation. The inclusion of basanite in the essexite series made the essexite line run parallel to the olivine-basalt line. If basanite were left out this series would have an inclination nearer to that of teschenite.

This correlation apparently applies also to other factors of differentiation and tends to support the contention of Smyth that « in the derived alkaline magma there is a concentration of the agents effecting their separation and, thus, their differentiation is cumulative, leading to great diversity of composition, with fractions relatively rich in rare elements » [1]).

The best illustration of this to be found in the variation diagrams is the bifurcation of the teschenite and olivine-basalt series at their alkali-acid ends. If we assume that the main line of the teschenite series runs from teschenite to the segregation vein; then the lugarite branch represents the intensification of diffusion differentiation superimposed on crystallization differentiation. The same applies to the phonolite branch of the olivine-basalt series, whose main line runs from olivine-basalt to rhyolite. There is a temptation to consider the end prongs as corresponding to the two conjugate magmas, but an actual comparison of analyses lends no support to this idea. It is quite obvious, however, that alkali-volatile diffusion-differentiation superimposed on crystallization-differentiation will tend to raise the upper branch and correspondingly lower the remaining part of the main line (the reference is made to the alkali-silica variation diagram only).

On the other hand, quartz-dolerite does not show much effect of differentiation. Relatively scarce segregation veins and patches represent the residual liquid of crystallization-differentiation, but a small influence of diffusion-differentiation prior to the emplacement of the magma may be traced in the dolerite-pegmatite schlieren.

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1) C. H. Smyth, *op. cit.*, p. 46.

The diffusion-differentiation hypothesis may perhaps throw some light on the disputed question as to how far tectonic conditions determine petrogenesis. A suggestion made by SMYTH may be recalled in this connection. It is that in the more stable (kratogenic) regions the relatively long-durational undisturbed conditions of the magma may facilitate alkali-volatile diffusion, while in the orogenic regions, in the absence of these conditions, such differentiation would be impeded.

7. Summary

The study of the petrochemistry, eruptive sequence and relative amounts of the Scottish Carboniferous-Permian igneous rocks leads to their genetic classification into three principal and two co-lateral series.

The origin of the series is attributed to the influence of alkali-volatile diffusion-differentiation of the primary magma corresponding to olivine-basalt.

The origin of the separate members of the series is attributed to crystallization-differentiation and in a lesser degree to diffusion-differentiation.

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Flood basalts and fissure eruption

(Paper delivered at the Section of Volcanology, International Union of Geodesy and Geophysics, Edinburgh, Sept. 22, 1936).

I. Introduction

Basalt is overwhelmingly the most abundant lava-type. According to DALY the collective volume of the world's basalts is five times greater than that of all other lava-types combined [1]. The writer would put the proportion of basalt among the lavas of the world much higher even than this. The proportion of basalt is so great because basalt tends to occur in huge accumulations through what H. RECK and others have called mass-eruption, in far greater degree than any other type of lava.

In this paper the term *basalt* is used in H. S. WASHINGTON's sense [2] for dark, heavy lavas of essential plagioclase — pyroxene — iron-ore composition, in which the light and dark constituents are present in approximately equal proportions. The magmas may be slightly oversaturated and may then contain a little actual or virtual quartz, or they may be somewhat under-saturated and contain actual or virtual olivine and sometimes a little nepheline or analcite. Rocks of basaltic habit which carry large amounts of olivine and, or feldspathoids are, however, held to be outwith the definition of normal basalt, and to fall under the types known as ankaramite, oceanite, ankara-

[1] R. A. DALY, *Igneous Rocks and the Depths of the Earth*, 1934, p. 40.

[2] *Petrology of the Hawaiian Islands; I. Kohala and Mauna Kea, Hawaii*. Amer. Journ. Sci., 5, 1923, p. 469.

trite, basanite, nepheline-basalt etc. The writer adheres to the view put forward by W. Q. KENNEDY that there are only two fundamental basaltic magma-types, the tholeiitic and the olivine-basaltic (crinanitic), respectively over-saturated and under-saturated, which differentiate along entirely different lines, and form entirely different end-products [1]. It is the author's opinion that the undersaturated basaltic magma type, as typified by the average Pacific basalt, is the fundamental world-magma, from which all other igneous types (some peridotites perhaps excepted) have been derived by processes of differentiation and assimilation.

II. Types of basaltic accumulations

At any given period of earth history the crust consists of orogens and kratogens (KOBER), which suffer different kinds of tectonic movement, and in which the accompanying igneous suites differ in many ways. In regard to tectonic associations, therefore, it is believed that igneous rocks may be classed as :

1. Geosynclinal and orogenetic,
2. Epeirogenic or kratogenic.

It is not intended to develop this line of thought any further in this place except insofar as it concerns basalts. Basaltic magmas appear in both kinds of major tectonic units [2].

1. Geosynclinal Basalts

Basaltic magma in enormous bulk appears in the early part of the orogenic cycle during the growth of the parent

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1) *Trends of Differentiation in Basaltic Magmas*, Amer. Journ. Sci., 25, 1933, p. 239-56.

2) H. G. BACKLUND classifies basalts as, 1. Plateau-basalts ; 2. Geosynclinal basalts. These classes correspond closely to those given above. *Zur genetischen Deutung der Eklogite*. Geol. Rundsch. 2, 1936, p. 49.

geosyncline, For the most part these lavas seem to be true basalts, generally of submarine eruption, and therefore often showing « pillow » and allied structures. There is a tendency for geosynclinal basalts to become enriched in soda, producing the soda-rich types known as *spilite*. Dolerite, gabbro, peridotite and serpentine, in large and small intrusive masses, constitute the intercrustal associates of the surficial basalts. When the orogenic phase of the cycle supervenes and the fold-mountains rise over the site of the geosynclinal, the basic igneous rocks are involved in the movements along with the geosynclinal sediments, and are often affected by low-grade metamorphism which transforms them into the well-known « green rocks » or *ophiolites* which are such prominent constituents of fold-mountain zones of all ages [1]).

As the main subject of this paper is flood-basalts it is not intended to deal further with geosynclinal basalts except to remark that their collective bulk is believed to be of the same order of size as that of the great flood-basalt accumulations [2]).

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[1]) A comprehensive discussion of the ophiolitic suite is given by G. Steinmann, *Die ophiolithischen Zonen in den mediterränen Kettengebirge*, Congr. Geol. Internat. XIV Session Madrid, 1926, Fasc. 2. pp. 637-67.

[2]) A rough estimate of the collective bulk of the geosynclinal basalt suite (mainly Ordovician) of the early part of the Caledonian orogenic cycle in north-western Europe may be made as follows : In the Southern Uplands of Scotland the Arenig pillow-lavas are at least 1500 feet thick, and probably underlie a strip of country at least 100 miles long by 25 miles wide, as they appear at the summits of the anticlines throughout the Ordovician outcrop. Hence their bulk in the Southern Uplands alone may be as much as $100 \times 25 \times \frac{1}{4} = 625$ cubic miles. As pillow-lavas of the same age occur along the southern border of the Scottish Highlands, the total area covered by basic extrusive rocks may be more than twice as much as that of the Southern Uplands. Hence it is probably safe to estimate the bulk of geosynclinal basalts south of the Highland Border at 1000 cubic miles, i. e. 1000 cubic miles for each 100 miles along the strike. But the Caledonian fold-mountains, with identical igneous associations, extends south-westward into the

2. Epeirogenic (Kratogenic) Basalts

Practically all large accumulations of basalts, other than the above-mentioned geosynclinal basalts, occur within, and associated with the movements of, the great stable blocks or kratogens of the earth's crust, which may, of course, include ancient extinct orogens welded on to them ; or they occur within the oceanic segments, which are of the same order of size and suffer the same slow secular movements as the kratogens. It is probable that the floors of the Pacific and Indian Oceans, and of part of the Atlantic Ocean, expose the surface of the basaltic layer of the sub-crust. The average Pacific basalt, in particular, may approach most nearly the composition of the basaltic layer.

We may recognise three main types of basalt accumulation which, in order of increasing size, may be designated as, A. Multiple-vent basalts ; B. Shield basalts ; C. Flood basalts. It is the last-named which is the main subject of the present paper.

A) *Multiple-vent basalts*

In lieu of a better term I use the designation « multiple-vent » basalts to indicate accumulations arising from the confluence of lava flows from a large number of small and closely-spaced volcanoes. The flows coalesce into masses of the order of size of a few hundreds to a few thousands of square miles, and collective volumes of up to 1000 cubic miles. One of the best examples is the Carboniferous basaltic region of the Clyde (Scotland), which is found as a

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centre of Ireland, and north-eastward through the Scandinavian peninsula, and thence into Spitsbergen, with a possible extension into Greenland, a total distance of at least 3000 miles. If we can extrapolate from the Scottish area, the total bulk of Caledonian geosynclinal basalt may be of the order of 30000 cubic miles. And if, as is entirely probable, there is an equal bulk of dolerite, gabbro, peridotite and serpentine, the above figure may be doubled for the total amount of basic and ultrabasic igneous material included within the Caledonian geosynclinal.

number of faulted plateau remnants centred about the city of Glasgow. The lavas must originally have covered an area of over 2000 square miles, and were erupted from a series of over 70 small volcanoes. As the average thickness of the lavas is 1500 feet, the volume erupted during the Clyde Carboniferous igneous episode must have been of the order of 600 cubic miles. [1]) The Tertiary basalt area of Victoria (Australia) appears to represent another example of « multiple-vent » accumulation, [2]) as do also the numerous provinces, such as the Auvergne, Westerwald, Bohemian Mittelgebirge, etc., of the extra-Alpine forelands, in which basalts are the most prominent lavas.

J. W. Gregory [3]) restricted the term « plateau basalt » to this type of accumulation ; while H. Reck has proposed the term « areal eruption » [4]) Both terms are objectionable as they are indefinite, in some regards incorrect and, in any case, refer to inessential and accidental geographical features of the accumulations. I propose the term « multiple-vent basalts », although I am not altogether satisfied with it, as a more adequate descriptive term for this type of accumulation.

B) *Shield Basalts.*

Shield volcanoes represent a type of basaltic accumulation which has been recognised by most volcanologists. The small Icelandic examples are regarded as the most typical shield volcanoes, and Etna may perhaps be regarded

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[1]) G. W. Tyrrell, *Volcanoes* (Home University Library), 1931, pp. 186-9.

[2]) A. B. Edwards, *The Volcanic Rocks of Victoria*, Proc. Geol. Soc. London, No. 1932, Feb. 19 th. 1937, p. 52.

[3]) *Earthquakes and Volcanoes* (Benn's Sixpenny Library, No. 97), 1929, p. 37.

[4]) *Die Masseneruptionen unter besonderer Würdigung der Areal-eruption in ihrer systematischen und genetischen Bedeutung für das isländische Basaltdeckengebirge.* Deutsche Island. Forschung, 1930, pp. 24-49.

as a shield volcano in an early stage of its history. But hitherto the largest shield volcanoes, and indeed the largest single volcanoes in the world, have been thought to occur in the Sandwich Islands, especially in Hawaii. Stearns and Clark, however, have recently given reasons for regarding Mauna Loa and its neighbours, not as single colossal shield volcanoes, but as composite structures resulting from the accumulations of a series of shifting vents of shield type, such as Kilauea [1]). Mauna Loa is regarded as a great ridge built up of the products of ancient shield volcanoes, the earliest probably of Tertiary age, with a comparatively new shield volcano, Mokuaweoweo, capping the ridge and covering it with a veneer of new flows. If this view is correct, Kilauea, Mokuaweoweo, and the Icelandic shield volcanoes, probably represent the normal size of this type of volcano.

Confluent flows from neighbouring shield volcanoes, whether from the craters or from flanking fissures, give rise to basaltic accumulations many thousands of square miles in area, and with collective volumes running perhaps to 10000 cubic miles or more. Hawaii and the other Sandwich Islands, Iceland and perhaps Kerguelen, provide the best examples of such accumulations.

C) *Flood Basalts.*

Finally there are the basaltic accumulations of enormous size to which Sir A. Geikie's term « plateau basalts » has been universally applied, of which the Columbia Basalts and the Deccan Traps are the best-known examples. For these major accumulations I prefer the term « flood basalts » for reasons which will appear later. The order of size of flood-basalt accumulations is 50000 square miles or more, with a minimum volume of 20000 cubic miles.

[1]) H. T. Stearns and W. O. Clark, *Geology and Water Resources of the Kau District, Hawaii.* Water-Supply Paper 616, U. S. Geol. Surv., 1930, pp. 101-7.

It is with flood basalts and their mode of origin, with which the question of fissure eruption is involved, that it is proposed to deal with in the remaining part of this paper.

Review of Some Flood-Basalt Accumulations.

The youngest basalt flood is that of the Columbia and Snake Rivers plateau in the north-western United States, which occupies an area of over 200,000 square miles mostly in Washington and Oregon [1]. The Columbia region was formerly mountainous, but in Miocene times it was levelled up by enormous floods of basalt lava, and the former mountains now appear as islands and peninsulas projecting from a monotonous plain of lava. The Columbia and Snake Rivers have cut deep gorges through the plain, which expose in places almost the entire thickness of the formation. The plateau is built of a large number of thin, confluent, interlocking flows, between which occur slaggy surfaces, thin sheets of ash, and beds of lacustrine sediments. The supposed feeding dikes are numerous and narrow, seldom reaching 150 feet, and averaging less than 30 feet in width. Igneous activity has continued almost to the present day, especially in Oregon and Idaho, with the production of youthful-looking cones and craters, and fresh, slaggy lava flows. The average thickness of the plateau is estimated at 3,300 feet, and it is known to reach a maximum thickness of at least 5,200 feet. Hence the total volume of lava emitted must be of the order of 120,000 cubic miles. Great basaltic floods of about the same age and of the same general characters as that of the Columbia and Snake Rivers region occur in Syria and Arabia. [2]

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[1] Sir. A. Geikie, *Textbook of Geology*, 4 th. Ed., 1903, p. 344.

H. S. Washington, *Deccan Traps and Other Plateau Basalts*. Bull. Geol. Soc. Amer., 33, 1932, p. 775.

E. Blackwelder, *United States of North America*. Handb. d. Reg. Geol., VIII, Abth, 2, 1912, pp. 162-70.

[2] L. Dubertret, *Étude du régions volcaniques du Houran, du Djebel Druze et du Diret el Touloul (Syrie)* Rev. Géogr. Phys. et Géol. Dynam. Paris, fasc. II, 1929, pp. 275-321.

Another enormous basalt flood is that of the Deccan in Peninsular India, which occupies an area of 250,000 square miles [1]. As this formation is nearly 10,000 feet thick on the Bombay coast, and thins out towards the east and north, it is thought to have an equally large extension in the adjacent foundered parts of the Indian Ocean. Its total area may therefore, have been 500,000 square miles. This plateau again is built of numerous horizontal flows of basalt with partings of ash and sediments. At Bhusawal, Bombay Presidency, a boring encountered 29 distinct flows with an average thickness of 40 feet. Large dikes and other intrusive masses are found at a number of places around the margins of the basalt region, and there is a distinct hint of ring structure in the intrusion of Mount Girnar, Kathiawar [2]. The eruptions appear to have taken place towards the end of the Cretaceous, or at the beginning of the Eocene.

The Stormberg basalt lavas of South Africa, which occupy an area of 20,000 square miles in Basutoland alone, and there form the great mountain scarp of the Drakensberg, are regarded by Dr. A. L. Du Toit as mainly due to fissure eruption [3]. One hundred and fifty volcanic vents have indeed been found, and many more await discovery ; but the majority of these are filled with pulverized sedimentary materials, and have never emitted lava ; and the remaining active centres pierce the lowermost basalts only. The average thickness of the plateau appears to be about 3,000 feet, and individual flows are from 100 to 150 feet thick. Correlated basalt extrusions make up the 300-mile long Lebombo Range in the eastern Transvaal, and also

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1) D. N. Wadia, *The Geology of India*, 1919, pp. 192-201.

2) K. K. Mathur, V. S. Dubey and N. L. Sharma, *Magmatic Differentiation in Mount Girnar*, Journ. Geol., 34, 1926, 289-307. See especially Fig. 1 of this paper.

3) A. L. Du Toit, *The Geology of South Africa*, 1926. Karroo basalts, pp. 235-43 ; 256-7. Karroo dolerites, pp. 283-91. Also see, *The Union of South Africa*, Handb. d. Reg. Geol., VII, Abth. 7 a, 1929, pp. 140-2 ; and E. Krenkel, Geologie Afrikas 2. Teil; 1928, pp. 571-81.

a large area around the Victoria Falls in Rhodesia. The extrusion of these great masses of lava probably took place in early Jurassic times. The Stormberg lavas are intimately connected with the great Karroo dolerite sill-swarm, and with the norite-peridotite lopoliths of Natal ; and the relatively small lava fields of this episode, as compared with others, may be due to the fact that the greater part of the activity took place underground.

In recent years it has become clear that exact analogues to the Stormberg lavas and Karroo dolerites exist in the Paranà region of South America. The basalt flows in this region cover an area of over 300,000 square miles, with an estimated bulk of 50,000 cubic miles. They are associated with intrusive masses (mainly massive sills) which are found within a further area of 75,000 square miles [1]).

Basaltic lava fields of approximately the same age as those of South Africa and South America (Mid-Mesozoic) are also known in Tasmania, Antarctica, Peninsular India, and the eastern United States (Newark Series).

One of the oldest known basalt floods took place in Late Pre-Cambrian times over the Lake Superior region of North America. The volume of igneous material erupted in this episode is estimated at 24,000 cubic miles [2]). This flood was associated with a great sill-and dike-swarm, and with the enormous lopoliths of Duluth (Minn.) and Sudbury (Ont.) which, together with the lavas, brought in most of the valuable copper, silver, iron and nickel ores of the Lake Superior region and Ontario. There now appears to be ample evidence that the Keweenawan basalts were derived from extensive fissures lying near the present centre of Lake Superior [3]).

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1) C. L. Baker, *The Lava Field of the Paranà Basin, South America*. Journ. Geol. 31, 1923, pp. 66-79.

2) C. R. Van Hise and C. K. Leith, *The Geology of the Lake Superior Region*. U. S. Geol. Surv., Monograph 52, 1911, pp. 408-12.

3) C. K. Leith, R. J. Lund and A. Leith, *The Pre-Cambrian Rocks of the Lake Superior Region*. U. S. Geol Surv., Prof. Paper 184, 1935, p. 10.

The most closely investigated region of basaltic floods is undoubtedly the North Atlantic or Thulean region. These eruptions were of Eocene age, or even later, and probably covered a region extending from Antrim and the Hebrides to Greenland [1]). The fragmentation and subsidence of parts of this great plateau land led to the formation of the northern Atlantic Ocean. We are able to infer the existence of the Thulean plateau from the large remnants, consisting of thick piles of uniform basalt flows with sedimentary intercalations, which occur in West and East Greenland, Iceland, the Faröe Islands, the Inner Hebrides and Antrim. If the Wyville-Thompson submarine ridge which connects the Hebrides with Greenland through Iceland, is covered with basalt, as there is reason to believe, the total area of the Thulean basalt flood may have been of the order of a million square miles. The presently exposed areas, however, amount only to 60,000 square miles. The thicknesses of the several basalt masses in the above-mentioned regions average a few thousands of feet, with individual flows ranging from a few feet to over 100 feet in thickness. Dikes in enormous profusion, arranged in great parallel swarms, are associated with the lavas and volcanic centres; many, however, belong to a later part of the episode. Many large dolerite sills occur in the West of Scotland, the Faröes and Iceland [2]). The flood basalts of supposed fissure eruption origin represent only the first phase of Thulean activity, a *regional* phase. This was followed by a *local* phase in which numerous central

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[1]) The Scottish sub-region is dealt with in the following memoirs of the Geological Survey of Scotland (abbreviated titles): « *Tertiary Igneous Rocks of Skye*, 1904; *Geology of the Small Isles*, 1908; *Geology of Mull*, 1924; *Geology of Arran*, 1928; *Geology of Ardnamurchan* », 1930.

[2]) See, G. W. TYRRELL, *The Geology of Arran*, Mem. Geol. Surv. Scotland, 1928; F. WALKER, *Differentiation in the Sills of Northern Trotternish (Skye)*, Trans. Roy. Soc. Edin., LVII, Pt. I, 1932, 241-57; F. WALKER and C. F. DAVIDSON. *A Contribution to the Geology of the Faröes*, ibid., LVIII, Pt. III, 1936, pp. 869-97.

shield volcanoes were developed, in which differentiation produced a wide range of rock types arranged in the remarkable ring structures which were first fully described from the West of Scotland; [1]), and finally, by another *regional* phase which, however, seems to have been marked by dike injection only.

III. Characteristics of flood basalt accumulations

1. From the instances just given flood basalt accumulations are characterised by enormous area and volume. As above-mentioned the order of size may be given as 50,000 square miles or more, and of volume at a minimum of 20,000 cubic miles.

2. They are *lava floods* which submerge the theatre of eruption leaving only the higher parts of the region standing as islands and peninsulas above the sea of lava. This feature is particularly well seen in the Columbia and Snake River floods (p. 95), the youngest of the great basalt floods. Geological vicissitudes may obscure this relation in the more ancient examples, but it can always be made out by detailed field study. The following quotations from Sir A. Geikie emphasise this aspect of flood basalt eruption, or « plateau basalt » as he called it.

« ... there have been periods in the earth's history when the crust was rent into innumerable fissures over areas thousands of square miles in extent, and when the molten rock, instead of issuing, as it does in most modern volcanoes, in narrow streams from a central elevated cone, welled out from these rents or from numerous small vents along their course, and flooded enormous tracts of country without forming any mountain or conspicuous volcanic cone... » [2]).

« In former geological ages, extensive eruptions of lava, without the accompaniment of scoria, with hardly

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1) J. E. Richey, *Tertiary Ring Structures in Britain*. Tran. Geol. Soc. Glasgow., XIX, Pt. 1, 1932, pp. 42-140.

2) Sir A. Geikie, *Textbook of Geology* 4th edition, 1903, p. 264.

any fragmental materials, and with, at the most, only flat, dome-shaped cones at the points of emission, have taken place over wide areas from scattered vents, along lines or systems of fissures. Vast sheets of lava have in this manner been poured out to a depth of many hundred feet, completely burying the previous surface of the land and forming wide plains or plateaux. These truly « massive eruptions » have been held by Richthofen and others to represent the grand fundamental character of volcanism, ordinary volcanic cones being regarded merely as parasitic excrescences on the subterranean lava-reservoirs... » [1]).

In these passages Sir A. Geikie mentions many of the special characters of flood basalts. In particular the flooding of a region, which is frequently of diversified relief, by sheets of basaltic lava, seems to be characteristic. Sir A. Geikie actually mentions the word « flooded », and I hold that « flood basalt » is a much more fitting designation for this colossal type of basalt accumulation, which cover regions of enormous extent as a flood, than « plateau basalt », which merely refers to an accidental and inessential feature resulting from levelling-up, erosion or earth movement. The Columbia and Snake River basalt region is more often referred to as a plain rather than as a plateau. It is a great plain out of which mountains project, and which is bounded by mountains. It is not an elevated region of inconspicuous relief.

3. Basalt floods are poured out on continental surfaces and are usually of subaerial origin. There are many intermissions of the volcanic activity during which sediments of aeolian or lacustrine origin, including beds of wind-blown ash or tuff, old soils, bauxitic and lateritic deposits and even coals, may be formed, and covered by later flows.

4. Basalt-flood eruptions are marked by the almost complete absence of conspicuous cones or any surficial signs of central volcanoes. Local accumulations of agglomerate

[1]) Ibid., p. 343.

and ash produced in special ways may occasionally be enconuntered [1]).

5. Basalt floods exhibit an overwhelming predominance of lavas over fragmental materials of explosive origin.

6. The flows are relatively thin, averaging about 40 feet. Exact measurement of 37 Tertiary basalt lavas in Iceland by Tyrrell and Peacock (unpublished work) gave an average thickness of 42.5 feet. Keilhack's less accurate method of measurement of 226 basalt scarps in North-western Iceland gave 44.6 feet [2]). Hawkes, however, obtained an average of only 26 feet for 38 flows in the Eyjafjord region in the north of Iceland [3]). Fermor obtained an average of 40 feet for 27 Deccan Traps [4]). Many recent basalt flows from fissures in Hawaii are often less than 10 feet in thickness, and may dwindle down to a few inches at their terminations [5]). The Pahala Basalts of Pleistocene age have an average thickness of 15 feet [6]).

7. Basalt floods are associated with parallel dike-swarms, sill-swarms, and lopoliths of norite and gabbro. Naturally these features are found in greatest profusion in the older basalt fields, or when one of the younger basalt floods has been subjected to deep erosion.

In the youngest basalt floods, as, for example, that of the Columbia and Snake River region, the great mass of uneroded basalt sheets effectively blankets and conceals its foundations, and a considerable display of dikes, and even more of sills and lopoliths, cannot be expected. It is

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1) R. E. Fuller, *The Aqueous Chilling of Basaltic Lava on the Columbia River Plateau*, Amer. Journ. Sci., XXI, 1931, pp. 281-300.

2) K. Keilhack, *Beiträge zur Geologie der nordwestlichen Halbinsel von Island*, Zeitschr. Deutsch. Geol. Ges., 85, 1933, pp. 621-30.

3) L. Hawkes, *The Building up of the North Atlantic Volcanic. Plateaus*, Geol. Mag., (VI), 3, 1916, p. 385.

4) L. L. Fermor, Rec. Geol. Surv. India, LVIII, Pt. 2, 1925, p. 114.

5) H. T. Stearns, *The Keaiwa or 1823 Lava Flow from Kilauea Volcano, Hawaii*. Journ. Geol., XXXIV, 1926, pp. 336-51. — H. T. Stearns and W. O. Clark, op. cit. p. 77.

6) H. T. Stearns and W. O. Clark, op. cit., p. 65.

significant that the Karroo (Stormberg and Rhodesian) basalt flood of Mid-Mesozoic age, is accompanied by an immense sill-swarm, but by only a few small lopoliths; and that the largest known lopoliths, those of Sudbury (Ont.) and Duluth (Minn.), are associated with the Lake Superior basalt flood of Late Pre-Cambrian age.

IV. Mode of eruption of flood-basalts

The *fissure eruption* theory, promulgated by von RICHTHOFEN and popularised by Sir A. GEIKIE, has been almost universally accepted for the origin of flood basalts (« plateau basalts » in the old sense).

While no-one now believes, as apparently did von RICHTHOFEN, that flood basalts were poured out from fissures hundreds of miles in length and a mile or more broad, it is widely thought that they have originated from comparatively short and narrow fissures distributed over a vast area, by long-continued intermittent eruption in the manner graphically described in the above quotations from Sir A. GEIKIE.

This type of fissure eruption is thoroughly authenticated from descriptions of the present-day Hawaiian and and Icelandic examples. These descriptions show that delivery from elongated fissures, whether by quiet sheet-flood eruption from all parts of the fissure at the same time, or by more violent eruption from numerous separated points ranged along the fissure, is the essential feature of this eruptive type. Both the sheet-flood and cone-chain modes of fissure eruption have recently been described from Hawaii [1]. It seems probable that an eruptive episode may begin as a quiet welling-out of great volumes of highly-liquid basalt simultaneously from all points along the fissure, but that with the arrival of the more highly-gasified material which was the proximate cause of the upward movement of the superjacent magma, the eruption becomes more explosive. As the gases escape and the volcanic energy begins to wane,

[1]) H. T. STEARNS and W. O. CLARK, op. cit., pp. 77, 130 et seq.

the fissure becomes choked, eruption is localised at a few points, over which, in the final stages of eruption, the perfect little agglutinate- and ash-cones which commonly mark the site of the fissure are built up.

The late Professor J. W. Gregory denied the existence of fissure eruptions apparently on the ground that, while the lava, as in the Skaptarjökull or Laki eruption of 1783, rose up a fissure miles in length, it was discharged through a series of volcanic vents and not directly from the fissure [1]). This seems, however, unnecessarily to restrict the term fissure eruption merely to the sheet-flood type. That lava is delivered from a fissure, whether as a sheet-flood or from numerous small vents, seems to be the essence of the definition of the fissure mode of eruption. Moreover, it is inconceivable that great volumes of basalt (3 cubic miles in the Laki eruption) could have been emitted from the actual cones, and yet have left these fragile structures almost or quite intact. It is far more likely that the bulk of the lava was emitted as sheet-floods or from shifting points of eruption, and that the cones merely mark the sites of the feeble final spasms of activity.

The fissure eruptions of the present day are comparatively small affairs. That of the Skaptarjökull (Laki, 1783), with its volume of three cubic miles, appears to have been the largest fissure eruption of historical times. Stearns and Clark (op. cit.) point out that the Hawaiian flows are generally thin, often less than 10 feet thick at their sources and tapering distally to only a few inches. The intermittence of the flows from the Hawaiian fissures provides opportunity for soils and vegetation to appear on the surfaces of the lavas, only to be entombed by the next flow. The amount of explosively fragmented materials relatively to the enormous bulk of lava is quite insignificant.

At the conclusion of a fissure eruption the magma freezes in the fissure and forms a dike, as has actually been

[1]) *Earthquakes and Volcanoes,* Benn's Sixpenny Library, No 97, 1929, p. 36.

observed in Hawaii [1]) ; and at the end of a fissure eruption episode one or more parallel dike-swarms are left as witnesses of the mode of eruption. STEARNS and CLARK [2]) say that :

« The hypomagma of the Hawaiian Islands exists in a great mosaic of fissures, which are expressed on the surface in definite relatively narrow rift systems that are arranged in a more or less geometric pattern. This is the fundamental concept of volcanism in Hawaii, for the extravasation of the lava, the surface accumulations, explosions, and all other volcanic phenomena are controlled directly or indirectly by the ancient rift complexes ».

As the great recent basalt floods effectively blanket and conceal their foundations dikes are infrequently observed in such relatively uneroded regions of flood basalts as Hawaii, Iceland, and the northwestern United States. But innumerable dikes in extensive parallel swarms' occur in the deeply-eroded basement of Oahu and other islands in the Hawaiian group, while thick sills of coarse dolerite and gabbro have been observed [3]). The remarkable parallel dike-swarms and systems of thick basic sills of the Western Isles of Scotland, now classical in volcanic geology, are closely associated with the remnants of the eastern part of the great Thulean basalt flood [4]).

The dikes of the Tertiary dike-swarms of the West of Scotland were regarded by Sir A. GEIKIE as the feeders of the flood-basalt eruptions. This view is supported by the following quotation from STEARNS and CLARK (op. cit. p. 140) :

[1]) STEARNS and CLARK, op. cit., p. 48.

[2]) Ibid. p. 129.

[3]) H. T. STEARNS, in *Geology and Ground-water Resources of the Island of Oahu, Hawaii. Territory of Hawaii, Division of Hydrography, Bull. 1*, 1935, pp. 20, 95.

[4]) For an excellent general account of this region see, J. E. RICHEY, *Tertiary Ring Structures in Britain*, Trans. Geol. Soc. Glasgow, XIX, pt. 1, 1932, pp. 42-140 ; and British Regional Geology : Scotland : *The Tertiary Volcanic Districts*, Geol. Surv. 1935, 115 pp.

« The fact that profound seaward slip faults bring magma to the surface indicates that at depths of 3 to 4 miles there must be potentially fluid lava or large rifts filled with magma. The width of an active fissure rarely exceeds five feet and may be less. Large volumes of lava seem to have no difficulty in finding their way to the surface through narrow fissures. Exposures on Oahu and on Hawaii indicate that these feeders do not widen downward, at least in the first 4,000 feet. In fact, they may extend to the source of lava with essentially the same width ».

Because the dikes penetrate the basalt flows it has been contended by J. W. Gregory and others that the fissures represented by the dikes cannot have been the channels of delivery. In the Tertiary flood-basalt region of the West of Scotland the question is complicated by the fact that there are undoubtedly systems of dikes which are later than the early flood basalts. But there are also demonstrably early dikes of the same petrological and chemical characters as the flood basalts, which may be regarded as the feeders of the latter although no actual connections of dikes with the bases of flows have yet been demonstrated in this region. The lavas so effectively blanket and obscure their foundations, and the chances are so heavily against natural or artificial sections intersecting such junctions, that it will always be difficult to demonstrate the continuity of a dike with a flow. Nevertheless, F. Walker and C. F. Davidson in the Faröes [1]), R. E. Fuller in Idaho [2]), and W. T. Lee in Colorado [3]), have described this phenomenon.

Notwithstanding that in the great majority of examples the dikes cut parts of the sequence of basalt lavas, recent observations in Hawaii make it possible to imagine a mechanism whereby the dike-filled fissures could nevertheless have delivered lava to the flows that they undoub-

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1) *Trans. Roy. Soc. Edin.*, LVIII, pt. III, 1936, p. 875.
2) *Amer. Journ. Sci.*, XIV, 1927, p. 228.
3) *U. S. Geol. Surv., Bull. 352*, 1908, p. 54.

tedly penetrate. According to data by STEARNS and CLARK the same fissure may repeatedly emit lava with long intervals between the successive flows [1]. The fissure and the dike which has served all the flows must therefore break through the succession of lavas up to the last one emitted, and thus penetrates the whole series. The fissure is ultimately filled with the latest magma to be delivered, but it may nevertheless have served as the feeder of many of the earlier flows. Furthermore, each successive pulse of lava may eviscerate the fissure afresh, destroy all traces of connection with the preceding flow, and provide clean-cut contacts with the earlier flows. In a wide major fissure the cleaning-out process may well be incomplete, and in such a case the phenomenon of a *multiple dike* with its well-marked interior contacts, such as are of frequent occurrence in the Tertiary basalt fields of the West of Scotland, would be produced [2], Multiple dikes may yet prove to be one of the strongest evidences of fissure eruption.

Theory of *Areal Eruption* (H. RECK). In his recent work on the mass-eruptions of Iceland H. RECK (op. cit. supra), while admitting that fissure and shield eruptions may help to build up flood basalt accumulations, ascribes the bulk of the lava to what he calls « areal eruption », i. e. eruption from a multitude of small vents distributed over a wide area, which appears to be the same mechanism as that which I have called « multiple-vent eruption » (p. 92).

From the prevalence of small central eruptions in Iceland at the present day he reasons that the same type of eruptive mechanism must have operated to produce the great Tertiary basalt lava fields which constitute the foundations of Iceland. But the freedom of the Tertiary basaltic basement of Iceland from any traces of small grouped volcanoes is conspicuous. Recent extensive traverses by Dr.

[1] Op. cit. supra, p. 75.

[2] Mull Memoir, 1924, pp. 32, 356. Arran Memoir, 1928, pp. 247-8. Ardnamurchan Memoir. 1930, p. 63.

M. A. PEACOCK and the author [1]) over the western half of Iceland failed to disclose any signs of such areal activity, and also failed to find more than a very few and small masses of ash and agglomerate other than the wind-blown lateritic « red partings » which occur between many of the flows [2]).

It seems to be characteristic of flood-basalt eruption that, as the intensity of volcanic action declines, eruption comes to take place from point rather than from linear foci. These points may be grouped over more or less extensive areas (*areal eruption* of RECK), or may be ranged along lines over the major fissures, as exemplified by the present-day volcanicity of Iceland, Hawaii, and the recently-extinct volcanicity of the north-western United States. As the volcanic energy diminishes the lava apparently can only break through at specially favourable points such as the intersections of fissure systems, or through series of sieve-vents situated above molten intrusions at shallow depths. RECK seems to have concluded that this areal or multiple-vent activity was prevalent throught the whole of the Tertiary volcanic period in Iceland, whereas the author holds that it represents the decadent or expiring phase of an earlier flood-basalt eruptive activity.

Theory of *Shield-volcano Eruption.* The modern intensive research which has been carried out by the officers of the Geological Survey of Scotland on the Tertiary volcanic centres of the West of Scotland (see references, p. 98) has led back to the view with which J. W. JUDD's name is associated, that great central or shield volcanoes may have been the main sources of flood-basalt accumulations. Dr. J. E. RICHEY says : « Present-day research certainly tends to reaffirm the conception of JUDD that in Ardnamurchan, as in other Tertiary intrusive districts of the

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[1]) Memoir to be published shortly by the Geological Society of America.

[2]) These deposits have been convincingly explained by L. HAWKES, *The Building up of the North Atlantic Volcanic Plateaus*, Geol. Mag., (VI), 3, 1916, pp. 385-95.

West Highlands, what we now see exposed is the basal wreck of a great volcano » [1]).

Judd based his views on the then prevailing conception of the Hawaiian shield structures, under which they were regarded as single, huge, unitary volcanoes, the largest in the world, but resembling ordinary central volcanoes in every respect except size. The vent was considered to be of approximately the same diameter as the crater, and to communicate with a vast subterranean reservoir of magma. The new conception of the structure of Mauna Loa which has been developed by Stearns and Clark (op. cit.), following the long-continued researches on the structure and mechanism of Hawaiian volcanoes by Dr. T. A. Jaggar and other workers, is very different. They regard Mauna Loa and Mauna Kea as composite structures, not as single huge volcanoes. The present eruptive centre on Mauna Loa, the caldera of Mokuaweoweo, is regarded by them as a shield volcano of normal size which has been developed on the summit of an enormous ridge, itself composed of the products of earlier migratory shield volcanoes which have moved along one of the major rift-systems of Hawaii. Each of the component shield volcanoes produced its own caldera, with its circular bounding faults presumably occupied by ring-dikes, and was accompanied by a dike-swarm. The modern views regarding the position of the magmatic body and the channels of delivery of lava to the surface, are indicated by the quotations from Stearns and Clark given on pp. 104, 105.

On these views it is easy to see in the migratory ring-structures of the West of Scotland, and with better reason than Judd, the basal wrecks of a great line of shield-volcano complexes of Hawaiian type. The rings are mostly filled with gabbroidal rocks of the same magmatic type as the oversaturated or tholeiitic variety of the flood-basalts, or with dioritic and granitic differentiates from this magma. This fact appears to reinforce the view that what we now

[1]) Ardnamurchan Memoir, 1930, p. 78.

see at the present level of erosion is the final emplacement of magma in the ring-structures; and, while the rings break through the main mass of flood-basalts, there is no reason to disbelieve that they also represent the earlier foci of eruption, and were the centres from which even the earliest flood-basalts were erupted.

As we have already seen (p. 106) similar conclusions may apply to the earlier dike-swarms. The rifts are filled with the latest magma erupted, but may have served as the channels of delivery of earlier flows. The Tertiary dike-swarms of the West of Scotland are thus thought to be the analogues of the rift-zones of Hawaii. The great shield volcanoes are built up at the intersections of the rift-zones and shift their locations along rift-zones in accordance with changing geological conditions. When the ridge has been built up too high for the heavy basaltic lava to be lifted up to the crater by the available volcanic energy, the lava breaks out in fissure eruptions along the rift-zones on the flanks of the shield structures and in the hollows between adjacent cones. In course of time the surface will thus be more or less levelled up, and a typical flood-basalt accumulation will be produced.

Fissure eruption must thus be regarded as an invariable concomitant of the building-up of shield volcanoes. Even inside the great calderas themselves fissure eruption is the rule, as is proved by the observations of STEARNS and CLARK [1]).

We thus arrive at the view that flood-basalt accumulations are due to the combined operation of shield volcanoes and fissure eruptions. In their early stages the lava is emitted from the craters of the shield volcanoes, although even then it may be largely supplied from fissures. At a later stage, when the flat cone has reached the limit of growth set by the maximum available volcanic energy, ring-structure begins with collapse along circular faults consequent upon the declining magmatic pressure, forming

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[1]) Op. cit. supra, pp. 48-9.

calderas at the surface [1]). Further emission of lava takes place by fissure eruption on the flanks of the cones, and in the intervening hollows, along the rift-systems which have determined the sites of the volcanoes and the routes of their migrations.

This view has already been reached by Stearns and Clark [2]), although in a somewhat different form and with less emphasis on the concomitant ring intrusions which are, of course, not exposed in Hawaii.

These authors also draw a distinction between basaltic regions such as Hawaii, where the basalts are piled up in enormous flat elongated domes, and the more extensive region of the Columbia and Snake River plains (op. cit., p. 139) :

« The volcanic processes and rift-systems in the Kau District are similar to those in the great basalt plateaus of the world, except that in Hawaii large domes have been built instead of plains. The Snake River basalt plateau, in Idaho, lies in a region underlain by various types of rocks, which may be largely sedimentary and which as a rule contain many structural lines of weakness. The zones of movement in the complex underlying the plateau are probably wider than similar zones under Hawaii. Also, under this plateau the zone of movement is likely to shift as a result of continental adjustments that do not affect the Hawaiian Islands, because these islands are built up from the bottom of the Pacific Ocean. In the Snake River Plains it has been the migratory character of the volcanic rifts that has caused the basalt extruded to spread out over a wide area, forming a plain, rather than to remain

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[1]) See the analysis of the phenomena of the Askja (Iceland) caldera by C. T. Clough, H. B. Maufe and E. B. Bailey, in *The Cauldron-Subsidence of Glen Coe*, Quart. Journ. Geol. Soc., 65, 1909, pp. 666-9, following the observations of H. Spethmann, *Vulkanologische Forschungen im östlichen Zentralisland*, Neues Jahrb. Beil. - Bd., XXVI, 1908, p. 381.

[2]) Op. cit. supra, pp. 138-40.

stationary and build one or more lava domes. In Hawaii the permanency of the rifts has caused great domes to be built ».

H. Reck (op. cit. supra) has argued against the theory that shield volcano eruptive activity has been the main source of flood-basalt accumulations, on the ground that no signs of great central vents or calderas marking the sites of the volcanoes have been preserved. He has evidently overlooked the modern views of the structure of shield volcanoes which have been developed from study of the present-day Hawaiian examples and of the deeply-eroded Scottish centres. The vents of shield volcanoes of Hawaiian type are likely to be marked by the occurrence of rift-systems or dike-swarms combined with circular faults and ring intrusions. It is in these phenomena that we find evidence of the former existence of great central vents and calderas. Moreover, the existence of at least two great calderas within the Tertiary flood-basalts of the West of Scotland has been demonstrated in Mull [1]).

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1) Mull Memoir, 1924, pp. 131 et seq., 173, 179, 339 et seq.

Sir J. S. FLETT, F. R. S.

Report on British Volcanological Research during the period 1933-36

As there are no active volcanoes in Great Britain volcanological investigations are restricted to the examination of the structure, petrography and chemistry of extinct volcanoes. Reference may be made here, however, to the work of the Montserrat Committee which was instituted by the Royal Society on the recommendation of the British National Committee of the International Union of Geodesy and Geophysics to consider and report on the numerous earthquakes that had taken place in Montserrat (West Indies) during the last three years. These had caused apprehension among the inhabitants, who feared that the seismic shocks might be the precursors of eruptions and might be analogous to the Montserrat earthquakes which preceded eruptions in 1902 in St. Vincent, and in Martinique where they have continued at intervals. This Committee decided on a local investigation of the phenomena and in February 1936 sent out a geologist, Mr. A. G. MacGregor, of the Geological Survey (Scotland) and a seismologist, Dr. C. F. Powell of the Physics Department of Bristol University. They have now finished their work in the island and have returned to England. Their reports will in due course be submitted to the Royal Society. In connexion with the work of this Committee, Sir Gerald Lenox-Conyngham visited Montserrat, while Dr. T. A. Jaggar of the Hawaiian Volcanological Observatory and Mr. F. A. Perret, who maintains an observation station at Montagne Pelée in Martinique, have also made studies of the seismic and fumarolic activity in the island.

Tertiary Volcanicity. — In continuation of the work actively carried on in the Inner Hebrides and adjacent

mainland of Scotland during the last twenty years by the Geological Survey of Scotland, a model of the volcano of Ardnamurchan has been constructed for the Royal Scottish Museum under the superintendence of Dr. J. E. Richey (Geological Survey). A duplicate of this model is exhibited in the new Museum of Practical Geology, opened in London in 1935. Dr. Richey has also prepared a handbook descriptive of this model gaving a brief conspectus of the geology of Ardnamurchan. This handbook is published by the Geological Survey. Another new model of interest to volcanologists is that of the central district of the island of Mull, which shows in great detail the intricate structures and complicated succession of lavas and intrusions in this celebrated Scottish volcano. It was constructed by the Geological Survey of Scotland under the direction of the geologists who surveyed the ground and it serves as an illustration of the memoir on the Tertiary Geology of Mull, published by the Geological Survey (1924).

This model is the central exhibit in a section of the main floor of the new Museum of Practical Geology, London, and is surrounded by a display of maps, photographs, rocks and minerals illustrating the Tertiary volcanic province of Great Britain. Attention may also be drawn to other exhibits of volcanological interest prepared by the staff of tke Geological Survey for the new Museum of Practical Geology. A special section devoted to volcanic activity in general includes a map of the active volcanoes of the world and a diorama representing Vesuvius in action. Volcanic activity in Great Britain in past geological ages is well illustrated in regional exhibits that are concerned with the general geology of different districts of the country.

Further information on the remarkable 'ring structures' that characterize the volcanoes of Mull and Ardnamurchan has been provided by Dr. J. E. Richey in a paper descriptive of the Tertiary Ring Complex of Slieve Gullion (Ireland), published in the Quarterly Journal of the Geological Society of London, vol. LXXXVIII, 1932.

During the summer of 1934 and 1935 work has been carried on by the Geological Survey of Scotland in continuation of Dr. Harker's mapping of the southern part of Skye. Only preliminary reports have yet been published. The ground is occupied principally by lava flows and dykes with a few intrusive sheets. It is anticipated that before long the mapping of the volcanic rocks of the island of Skye will have been completed.

Dr. Cockburn has published in the Transactions of the Royal Society of Edinburgh the first complete account of the geology of St. Kilda, an outlying member of the Hebridean volcanic province.

Dr. Frederick Walker in continuation of his investigations of the sills of the dolerite isles of the North Minch has described those of Northern Skye. Mr. Davidson has described the crinanitic dykes and sills of the island of Raasay. Dr. W. Q. Krnnedy has brought forward a discussion of the central and plateau types of basaltic magmas and their relations in Scotland and in the rest of the world. The following list gives the principal items that have recently been contributed to the Tertiary volcanology and petrography of Great Britain.

Walker, F. 1931 " The Dolerite Isles of the North Minch.,, *Trans. Roy. Soc. Edin.*, vol. LVI, p. 753.

Richey, J. E. 1931-2. " Tertiary Ring Structures in Great Britain ,,. *Trans. Glasgow Geol. Soc.* vol. XIX.

Walker, F. 1932. " Differentiation in the Sills of Northern Trotternish, Skye. *Trans. Roy. Soc. Edin.*, vol. LVII, p. 241.

Kennedy, W. Q. 1933. " Trends of Differentiation in Basaltic Magmas ,,. *Amer. Journ. Science*, vol. XXV, serie 5 p. 239.

Tomkeieff, S. I. 1934. " Differentiation in Basalt Lava, Island Magee, Co. Antrim. ,, *Geol. Mag.*, vol. LXXI, p. 501,

Cockburn, A. M. 1935. " The Geology ef St. Kilda ,,. *Trans. Roy. Soc. Edin.*, vol. LVIII, pag. 511.

DAVIDSON. C. F. 1935. " The Tertiary Geology of Raasay, Inner Hebrides ,,. *Trans. Roy. Soc. Edin.*, volume LVIII, p. 375.

WALKER, F. 1934. " The Term Crinanite ,,. *Geol. Mag.*, vol. LXXI, p. 122.

TOMKEIEFF, S. I & C. E. Marshall. 1935. " The Mourne Dyke Swarm ,,. *Quart. Journ. Geol. Soc.*, vol. XCI, p. 251.

ALLISON, A. 1936. " Tertiary Dykes of Craignish, Argyll ,, *Geol. Mag.*, vol LXXIII, p. 73.

Many interesting investigations have also been made during the period under review regarding the characters of the pre-Tertiary volcanoes of Great Britain but these may perhaps be considered as more strictly belonging to petrography and structural geology than to volcanology as at present defined. Mention may be made, however, of the series of handbooks now being published by the Geological Survey of Great Britain which give concise accounts of the Geology of various districts of Britain with an index to the relevant literature. Of these the following are of special interest to volcanologists:

Scotland: The Tertiary Volcanic Districts. By J. E. RICHEY.

Pp. 115 + 9 plates, 57 figures in text.

The Midland Valley of Scotland. By M. Macgregor and A. G. Mac Gregor.

Pp. 89 + 8 plates, 16 figures in text.

The South of Scotland. By J. Pringle.

Pp. 97 + 7 plates, 14 figures in text.

South-West England. By H. Dewey.

Pp. 75 + 12 plates, 20 figures in text.

North Wales. By Bernard Smith and T. N. George.

Pp. 92 + 12 plates, 30 figures in text.

Northern England, By T. Eastwood.

Pp. 76 + 8 plates, 26 figures in text.

AXEL GAVELIN
DIRECTOR OF THE GEOLOGICAL SURVEY OF SWEDEN

Summary Report of the Researches in Sweden on Volcanic and related Phenomena during the period 1933-1936

As Sweden has no recent volcanos, the youngest manifestations of volcanic activity in the proper sense of the term being only a number of highly eroded eocen basaltic necks in Scania and small remnants of two old-tertiary volcanos of rhyolitic and andesitic composition in Småland and Hälsingland, the researches on volcanic phenomena in this country are restricted to formations of older, mostly pre-Cambrian, ages.

In the pre-Cambrian areas of Sweden the investigations have been prosecuted concerning the chemical compositions and the differentiation processes in the magmas, the tectonics of the great Archaean magma masses and the varying, mostly very strong, metamorphosing influences of these magmas. Especially in the central and northern parts of the country thorough studies of pre-Cambrian lavas and tuffs have been carried out in later years.

As for the recent displacements of magma masses in the interior of the earth beneath the Fenno-Scandian territory many investigations of later time have had for their main object to determine the isostatic fluctuations of the sea-level in Quaternary times, thus in order to enable us to settle with greater exactitude the amount of the apparent upheaval of the differents parts of Fenno-Scandia which is due to a real uplift of the land masses.

The results of these researches concerning volcanic and related phenomena are described in a great number of publications, among which may be mentioned: The publications of the Geological Survey of Sweden, Geologiska Föreningens Förhandlingar; Bulletin of the Geological Institution of the University of Upsala, the publications of Vetenskapsakademien, Lunds Universitets Arsskrift, Ymer, Geografiska Annaler, a. o.

O. B. BØGGILD

Report of the danish volcanological literature for the years 1933-36

The only work of any significance given out in these years is the paper of Dr. Niels NIELSEN : Contributions to the Physiography of Iceland with particular Reference to the Highlands West of Vatnajökull. Det Kgl. Danske Vidensk. Selsk. Skrifter, Naturvidensk. og Mathem. Afd. 9 Række IV. 5. 1933.

The country West of Vatnajökull is a region of the most intense volcanic activity, not alone in Iceland but, to be sure, it exceeds in that respect all other region of the same size in the whole earth. In the northern part of the district, the Háganga region, we mostly find very large lava eruptions originating from large fissures, and rather few explosive centra. In the rather small southern part, especially around the Fiskivötn, we find, on the other side, a highly complicated eruptivity, with an enormous number (more than 100) foci many of which are of very small dimensions. As an example I only shall point out one « complicated maar » into which there are found 14 smaller foci, partially maars and partially lava eruptions.

Other parts of the work deal with the tectonic conditions, the subaerial denudation, the aeolic processes and other exogene phenomena. In a last chapter there is set forth a new theory about Iceland' s volcanics and tectonics in the light of the Wegener' s theory : The Icelandic faults are assumed to have been formed in connection with a universal tension of the whole country in opposition to the faults in most other parts of the world the formation of which is connected with a pressure.

The work is illustrated with a lot of good pictures.

In the month of march 1934 a great eruption took place of a large volcano under the Vatnajökull, and as soon as possible Dr. Nielsen started an expedition, together with other scientists, to the place for having occasion to examine the volcano which is otherwise perfectly burned under the ice and which has never before been visited. He succeeded in reaching the place but the craters themselves were not accessible because of the volcanic activity. He, therefore, started a new expedition in 1936 to the same place. The results of these expeditions have not yet been published and shall be put off to a later report. At the same occasion Dr. Nielsen also began an examination of the palagonite formation which has proved to be of an exceedingly complicated nature.

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Volcanic Activity in Japan during Period between September 1933 and July 1936

(with 4 plates and 1 map)

The following summary is essentially that given by H. Tanakadate in his two papers ;

« Volcanic Activity in Japan during the Period between June 1931 and June 1934 » (Japanese Journal of Astronomy and Geophysics, Vol. XII, No. 1, 1934) and « Volcanic Activity in Japan during the Period between July 1934 and October 1935 » (Idem, Vol. XIII, No. 2, 1936) ; the latter was presented to the meeting.

1. Probable secondary phenomena having no connection with the deepseated magma

A) *Solfataric activities.*

Noboribetu crater in Hokkaidô ; this, one of the famous hot springs of Japan, showed solfataric activities in the months of May and August 1936.

Kurokura-Yama in Northeast-Japan has been showing a solfataric activity issuing since the autumn of 1935.

Iwate-San in Northeast-Japan : Fumaroles active in March 1935. First activity since 1719.

Hakone-Yama in Central Japan : Solfataric explosions occurred in the active crater in 1933. New solfataras have formed in 1934 on one of the central cones.

Hakusan standing in Middle Japan and near the coast of Japan Sea : Last explosive action was in 1575. Some new solfataras have been noted in early spring months 1935.

Kirisima-Yama in Kyûsyû consists of a long zone of cones extending NW-NE. Slight activity in July 1934 with mud explosions in one of the crater lakes were noted.

Iô-Torisima : An island volcano far off south of Kyûsyû : Last eruptive activity was in 1903. Apparently some new solfataras have formed in July 1934.

B) *Sulphur Eruption.*

Siretoko-Iô-Zan in Northeast-Hokkaidô : this volcano had been dormant after having last issued liquid sulphur and hot water in the years 1889 and 1890. Early in 1936 it became active again and continued erupting for several months, the eruptions taking place in the following order in May of that year.

1) Liquid sulphur eruption, 2) Explosive emission of hot water and steam, 3) Intermittent gushing of boiling water and steam, 4) Dormancy of 4-5 days.

At times thousands of tons of sulphur were expelled by a single eruption, the molten sulphur flowing 1,5 km into a narrow valley and finally pouring into the sea. This sulphur is 99 % pure and its total volume is estimated to be more than 200,000 tons.

The cause of this sulphur eruption might be the following. The increased heat in the volcanic vent melted the sulphur wich had filled the fissures and cavities of the volcano body being deposited by the issuing gas for many years. The melted sulphur then gathered in a subterranean lake of boiling water (we imagine such a boiling lake as that of Noboribetu in Hokkaidô in the inner part of the volcano). Such a subterranean boiling lake might cause a geyser of hot water carrying liquid sulphur.

2. Epigonal Phenomena following former great outbursts

Komagadake in Hokkaidô : Although the after-effects of the big eruption of 1929 are nearly spent, new fissures have formed in July 1935 on the bottom floor of the caldera, vomitting strong sulphuric gas and ash.

Sakurazima in Kyûsyû: One of its greatest eruptions took place in 1914. In 1935 there were eruptions of smoke and ash with some considerable damage to near by farms.

3. Probable preludes to coming eruptions

Mihara-Yama in Ôsima in central Japan: Recently this volcano has been comparatively calm. In April 1934 smoke increased and in April 1935 fearful rumblings were noted, and red hot scoriae were thrown up from the crater on the bottom floor.

Yakedake in Central Japan: This volcano alternates in eruption with Asama-Yama. At present, as the latter is very active, this is comparatively calm, but strong detonations and earthquakes were noted in September 1934.

4. Explosive outbursts

A) *New explosions after a long dormancy.*

Iô-Yama in Paramusir island at the northern part of Kuriles, has entered, since October 1934, on a new period of activity for the first time in history. In December 1934 and in August 1936 large explosive eruptions took place. It shows at present periodic pulses of explosion.

Harumukotan volcano on the island of the same name in the middle part of Kuriles: The volcano showed ash explosions in autumn months of 1931. In January 1933 a big explosive eruption occurred and caused big avalanches and a *tunami*.

Tarumai-San in Hokkaidô; in December 1933 several explosions occurred on the caldera floor at the northern foot of the lava dome which rose in 1908. A new fissure 250 m long and 7 m wide was formed by the explosive eruption.

Akita-Komagadake in Northeast-Japan which was considered as an extinct volcano waked suddenly its activity in July 1932, forming many fissures and craterlets in the

forest on the caldera bottom. In March 1933 local tremblings were noted but no activity was observed.

Kutinoerabu an island volcano far off south of Kyûsyû showed an explosive eruption in 1931, and again in December 1933 strong outbursts were noted and were followed by a large explosion in the January of next year.

B) *Augumentation of Eruptions in the active Volcanoes.*

Asama-Yama in Central Japan : On this, one of the most active volcanoes in Japan, a observatory for Tôkyô Imperial University was inaugurated in 1934. The volcano made a strong outbursts in 1935 and entered on a new period of activity with repeated explosions of the volcanian type. Depression and then elevation of the crater floor occurred at first in 1934, then they were followed by great explosions in April-May 1935, which continued on to the end of the period under review.

Phenomena predicting the approach of an explosion have been recognized, as follows. A) Upswelling of the bottom floor of the crater. B) Frequent volcanic earth tremors. C) Tilting of the earth surface in the neighbourhood of the volcano. D) Extraordinary changes in earth current.

Aso-San in Kyûsyû on which the Observatory for Kyôto Imperial University is situated, was active in the close of the year 1932, in the months February, May and September 1933. Then in the year 1935 the activity increased again during first half of the year. Ash and scoriae were emitted at various times and also smoke clouds. Interesting results obtained at the above mentioned observatory are as follows.

A) Classification of micro-tremors into four groups with full explanations as to their mechanisms. B) Determination of the depht of centers of certain eruptive earthquakes as 860 meters. C) Determination of the initial velocities of ejecta, as 30 m/sec. to 94 m/sec. varying according to the quantity of volcanic gases explosively evolved from the magma, and not to the dept at which the eruption earthquake occurs.

5. The Formation of New Volcanoes

Taketomi-Zima : Near the island volcano Alaid at the northern end of the Kuriles a submarine eruption occurred, and a new islet appeared in January 1934, as a cinder cone 120 m high above the sea level. Basalt aa lava was erupted from the crater of the new cone and covered the northern foot of the volcano. The lava was the most basic of those of recent origin in Japan.

Io-Zima-Sintô : Near Iô-Zima, an island volcano far south of Kyûsyû, a submarine eruption occurred. After long Subaqueous eruptions with abundant quantity of smoke and pumice, a new volcano appeared in December 1934 above the sea surface and showed strong eruptions. The erupted pumiceous lava is acidic, as most of those recently formed in Japan with 70 % $Si0_2$. In January 1935 two new lava islets were formed of which the smaller one soon afterwards disappeared, leaving the other ; a lava dome which now stands 300 m high above the former sea bottom and 25 m high above sea level.

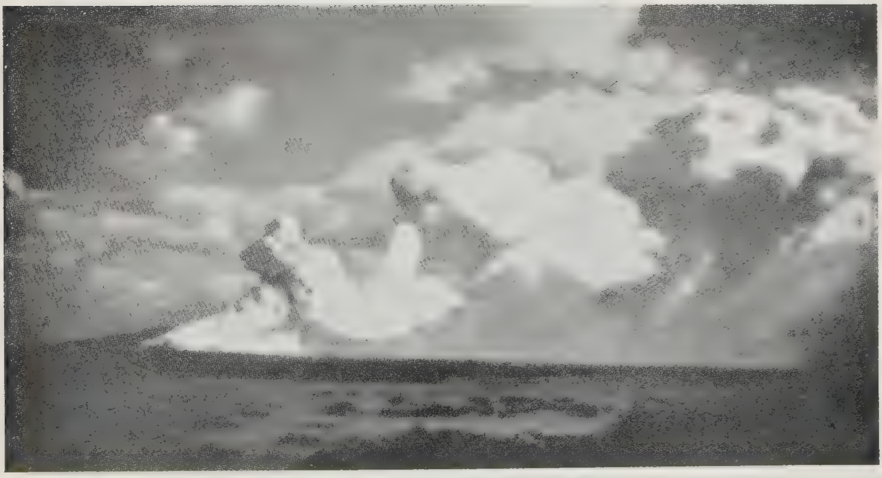
H. TANAKADATE — *Volcanic Activity in Japan during Period between September 1933 and July 1936.*

Fig. 1. — Taketomi volcanic islet.
View to the north from S. S. Hakuhô Maru.
Left ; a part of the eastern piano of the island volcano Alaid. The new islet cone stand about 600 m. far from the eastern shore of the Alaid island and its height was estimated to be 50 m. a. s. l.
(Photo. by Captain Taketomi on January 26 th. 1935).

Fig. 2. — Taketomi volcanic islet.
View to the south from the main island of Alaid.
(Photo. by Author on September lst. 1935).

Fig. 1. — Taketomi volcanic islet.

View to the south from the end of the lava plateau which is extending at the northern foot of the new formed cone. Basic a - a lava in front, dissected cone in rear. (Photo. by the Author on September 1st. 1936).



Iô - Zima - Sintô.

Intermittent explosive eruption in the beginning of the subaerial eruption.

View to east from the eastern shore of the Iô-Zima, about 1800 m. from the eruptive center.

(Both photo. by the Author on 18th January 1935).

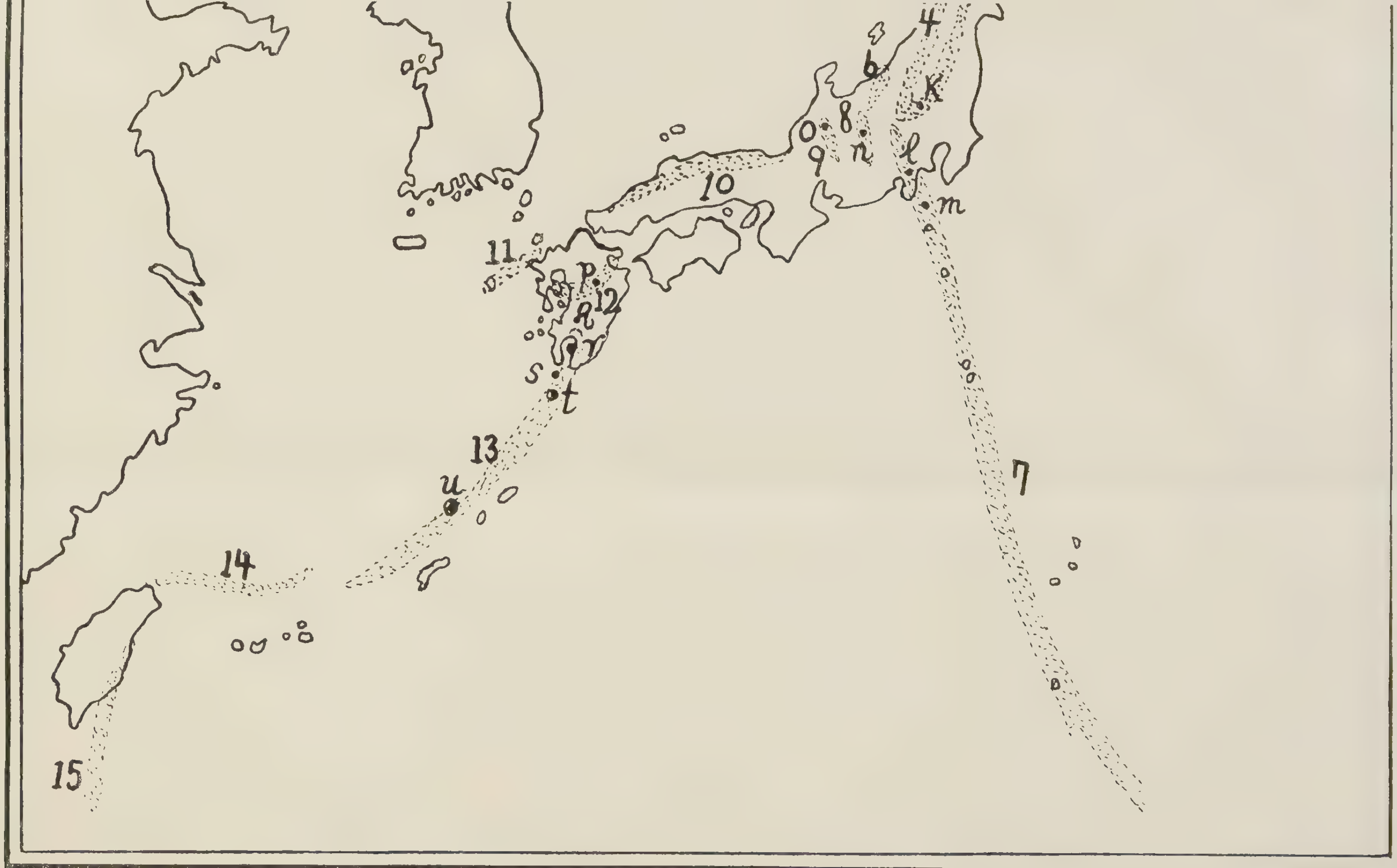
1936 – III

1935 – I

Iô – Zima - Sintô.

Right ; View from a standing point on the eastern flank (about 520 m. high a. s. l.) of Iô-Dake volcano on Iô-Zima and about 2.2 km. far off the submarine eruptive center. In the rear Takesima volcanic island.
(Photo. by the Author on January 21st., 1935).

Left ; View from the same stand point. The top of the submarine dome makes an islet consisting of pumiceous lava. The island is 500 m in E-W long, 200 m. in N-S wide and the height is about 25 m. a. s. l.
(Photo. by Author on March 31st., 1936).



a) Taketomi islet, b) Iô-Yama, c) Harumukotan volcano, d) Siretoko-Iô-Zan, e) Tarumai-San, f) Noboribetu, g) Komagadake, h) Kurokura-Yama, i) Iwate-San, j) Akita-Komagadake, k) Asama-Yama, l) Hakone-Yama, m) Mihara-Yama, n) Yakedake, o) Hakusan, p) Aso-San, q) Kirisima-Yama, r) Sakurazima, s) Iô-Zima-Sintô, t) Kutinoerabu, u) Iô-Torisima.

Volcanic Zones
1. Tisima
2. Risiri
3. Nasu
4. Tyôkai
5. Kanpû
6. Myôkô
7. Huzi
8. Norikura
9. Hakusan
10. Taisen
11. Gotô
12. Aso
13. Kirisima
14. Taiton
15. Taitô
1
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a
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e
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h

B. G. ESCHER
DE L'UNIVERSITÉ DE L'ÉTAT À LEIDEN, PAYS BAS

Rapport sur les phénomènes volcanologiques dans l'Archipel Indien pendant les années 1933, 1934 et 1935 et sur les ouvrages de volcanologie publiés durant ces années, concernant les volcans des Indes Néerlandaises.

(Avec 1 carte et 23 figures)

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Zeitschr. f. Vulkanologie. 1933 Bd. 15, pp. 1-7.

II. Phênomènes volcaniques dans les Indes Néerlandaises pendant les années 1933, 1934 et 1935.

G. L. L. Kemmerling fit en 1926 dans le Bullètin Volcanologique (No. 7 et No. 8) une carte des volcans actifs des Indes Néerlandaises et dressa un tableau comprenant la liste de 90 volcans. L' année suivante parut dans le « Bull. of the Netherlands East Indian Volcanological Survey » (décembre, No, 2) un tableau avec une carte de 102 volcans actifs. Au cours des dernières années, d'autres volcans s'ajoutèrent à ce nombre. M. le dr. Ch. E. Stehn mit au point l' état actuel de la connaissance du volcanisme dans les Indes Néerlandaises dans un article de la même revue (juin 1936, No. 75), où sont comptés 125 volcans actifs. C' est à cet article que nous empruntons le tableau et la carte des volcans à laquelle nous renvoyons pour leur position géographique.

Tableau des volcans actifs des Indes Néerlandaises

D'après le « Bulletin of the Netherlands Indies Volcanological Survey ».

No. 75, June 1936, par le Dr. Ch. E. Stehn.

● Volcans qui ont depuis 1600 eu des éruptions magmatiques ou bien des périodes d'activité croissante.

○ Volcans dans la phase fumerollienne, dont des éruptions magmatiques ne sont pas connues depuis 1600.
+ Champs de fumerolles et solfatares.

SUMATRA

103	Silawaïh-agam (Goudberg)	○	
1	Peuëtsagoë	●	1919-20
2	Boer ni Telong	●	1856 ?
3	Sibajak	○	
4	Sinaboeng	○	
5	Poesoek Boekit-Samosir	○	
119	Helatoba-Taroetoeng	+	
6	Boeal Boeali		
	a) Harinte na Godang	+	
	b) Sitoemba (Barerang)	+	
7	Sorikmarapi	●	1917
8	Talamau (Ophir)	○	
9	Marapi (Fort de Kock)	●	1927
10	Tandikat	●	1924
11	Talang	●	1845
12	Kerintji (Peak of Indrapoera)	●	1908
13	Koenjit	○	
14	Soembing	●	1926 ?
118	Blerang Beriti	○	
115	Boekit Daoen	○	
15	Kaba	●	1918
16	Dempo	●	1908
116	Boekit Loemoet Balai	+	
17	Sekintjau Belirang	○	
117	Pematang Bata	+	1933
109	Hoeloebeloe	+	
104	Radjabasa	○	
18	Krakatau	●	1935

JAVA

19	Poelasari	○	
20	Karang	○	1884 ?
21	Salak	○	1935

22	Kawah Tjibeureum-Tjibodas . . .		
	a) Kawah Tjibeureum.	+	1925
	b) » Taman	+	
	c) » Tjibodas	+	1935
	d) » Tjipamatoetan.	+	
23	Kawah Parabakti	+	
24	Gedeh	●	1886
25	Tangkoebanprahoe	●	1929
26	Patoeha (kawah Poetih)	○	
	a) Kawah Tjiboeni.	+	
	b) » Hedjo	+	
	c) » Tiis	+	
	d) » Tjiwidej.	+	
27	Waiang-Windoe	○	
28	Goentoer	●	1843
29	Kawah Kamodjan	+	1929
30	» Manoek	+	
31	Papandajan	●	1924-25
32	Galoenggoeng	●	1918
33	Telaga Bodas	○	
34	Kawah Karaha	+	
35	Tjerimai (Tjareme).	●	1805
36	Slamet	●	1934
105	Boetak Petarangan.	○	1928
37	Diëng volcanoes		
	a) Pakoewodjo	●	1826
	b) Igir Binem	○	
	c) Pangonan	○	
	K. Sikidang	+	
	K. Sigadjah	+	
	K. Koembang	+	
	K. Sibanteng.	+	
	K. Oepas	+	
	Telogo Teroes	+	
	d) Kawah Sileri.	○	
	e) Pagerkandang	○	
	K. Pagerkandang	+	
	K. Sipandoe	+	

	K. Siglagah	+	
	f) Bitingan	+	
	g) Tjondrodimoeko.	+	
38	Soendoro (Sendoro)	●	1906
39	Soembing	○	
40	Merbaboe	○	1570 ?
41	Merapi (Central Java)	●	1933-35
42	Oengaran	○	
43	Lawoe	○	
44	Wilis	+	
45	Keloed	●	1919-20
46	Ardjoeno-Welirang	○	
47	Bromo	●	1930
48	Semeroe	●	1913
49	Lamongan (Lemongan)	●	1898
50	Hijang-Argopoero	○	
51	Raoeng	●	1928-29
52	Kawah Idjen	●	1917

Petites îles de la Sonde

BALI

53	Batoer	●	1926
54	Agoeng	●	1843

LOMBOK

55	Rindjani	●	1915

SOEMBAWA

56	Tambora	●	1815
57	Sangeang Api	●	1911

FLORES

58	Wai Sano	+	
59	Wai Kokor	+	
60	Iniё Lika	●	1915
61	Ineri (Iniё Rie)	●	1911

62	Amboeromboe (Keo Peak)	●	1855
63	Poei ou Medja	●	1871
64	Ija ou Endeh api	●	1882
65	Keli Moetoe	●	1835 1860-70 ?
66	Soekaria Caldera	○	
110	Ndetoe Napoe	-	
67	Egon	●	1907 ?
68	Lewotobi Perampoean.	●	1935
69	Lewotobi Lakilaki	●	1932
111	Ili Moeda	○	
70	Leweno (Leroboleng)	●	1881
112	Riang Kotang	+	
71	Paloeweh (Paloë)	●	1928

Volcans situés entre Flores et Wetar

106	Ili Boleng (Adonara)	●	1885
72	Ili Lewotolo ou Wiriran (Lomblen) .	●	1931-32
73	Ili Labalekan . . . (id.) .	●	1931-32
74	Ili Weroeng . . . . (id.) .	●	1928
75	Batoe Tara	●	1849-52
76	Siroeng (Pantar)	●	1934

MOLUQUES et NOUVELLE GUINÉE

Mer de Banda

77	Damar	●	1892 ?
78	Teon	●	1693
79	Nila.	●	1932
80	Seroea	●	1921
81	Manoek	○	
82	Banda-Api	●	1901
83	Api, au nord de Wetar	●	1699
107	Nieuwerkerk (volcan submarin). . .	●	1927 ?
108	Emperor of China (volcan submarin).	●	

HALMAHEIRA

96	Doekono (Maloepang Magiwe) . . .	●	1933-36
125	Maloepang Warirang	○	
97	Iboe	●	1911
98	Todoko	○	
99	Gamkonora	●	1926
100	Peak of Ternate	●	1933
101	Motir	●	1744
102	Makian	●	1890

NOUVELLE GUINÉE

114	Oemsini (Arfak).	●	1864 ?

Célèbes et îles Sangi

MINAHASSA

89	Tongkoko (Batoe angoes)	●	1821
90	Klabat	○	
91	Lokon	●	1930
120	Empoeng	○	
92	Mahawoe	●	1904
93	Tampoesoe	+	
121	Lahendong	+	
122	Sarongson	+	
94	Sopoetan (Aesepoet)	●	1924-25
123	Sempoe (Kawah Masem)	○	
124	Batoe Kolok	+	
113	Tempang (Tempaso)	+	

BAIE DE TOMINI

95	Oena-oena	●	1898

ARCHIPEL SANGI

84	Submarine volcano (W. of Sangihe) .	●	1922
85	Awoe	●	1931
86	Banoea Woehoe (Mahengetang) . .	●	1918

87 Api Siaoe . . . . ● 1935
88 Roeang . . . . ● 1914

On verra dans la bibliographie, deuxième partie, dressée suivant les volcans actifs, lesquels parmi eux furent actifs, pendant les années 1933, 1934 et 1935. Je désire seulement attirer ici l'attention sur quelques éruptions importantes ou remarquables.

No. 117 Petamang Bata.

A Sumatra, l' activité volcanique dans la plaine de *Soeoh* (no. 117) fut particulièrement importante (5° 14′ latitude sud. 104° 16′. longitude est, 240 m. au-dessus du niveau de la mer). Un heureux hasard fit que la région ait été levée géologiquement en 1930, par le « Dienst van den Mijnbouw in Ned. Indië » (Service des Mines dans les Indes Néerlandaises), peu de temps avant l' éruption, de sorte que nous connaissons quel fut l'état de la dépression du *Soeoh* avant l'éruption. Van Bemmelen considère cette dépression comme faisant partie d' une des trois dépressions **volcano-tectoniques** de la vallée du Semangka (fig. 1) La dépression du *Soeoh*, en forme de losange, est bornée, au sud-ouest, par la faille du Pematang Sawah, longue de 11 km., au nord-ouest par la faille entre la plaine te l'Antatai-horst, longue de 6 km. Dans cette faille apparurent de nombreuses sources chaudes, à 98° C, ayant en partie le caractère de geyser, avec formation de terrasses de travertin silicieux et de solfatares. Les cratères et les matières volcaniques récentes faisaient défaut. La plaine est bornée au nord-est par un plan de faille long de 6 km., au pied duquel surgirent des sources de 40 à 50° C. Elle constituait donc un champ de solfatares à faible activité.

L'explosion phréatique, qui commenca le 10 juillet 1933, fut la conséquence du **tremblement de terre** de proportion désastreuse dans la partie méridionale de Sumatra, du 25 juin 1933. Sur cet important tremblement de terre parurent dans la « Natuurkundig Tijdschrift v. Ned. Indië », tome XCIV, fascicule I, les compte-rendus suivants :

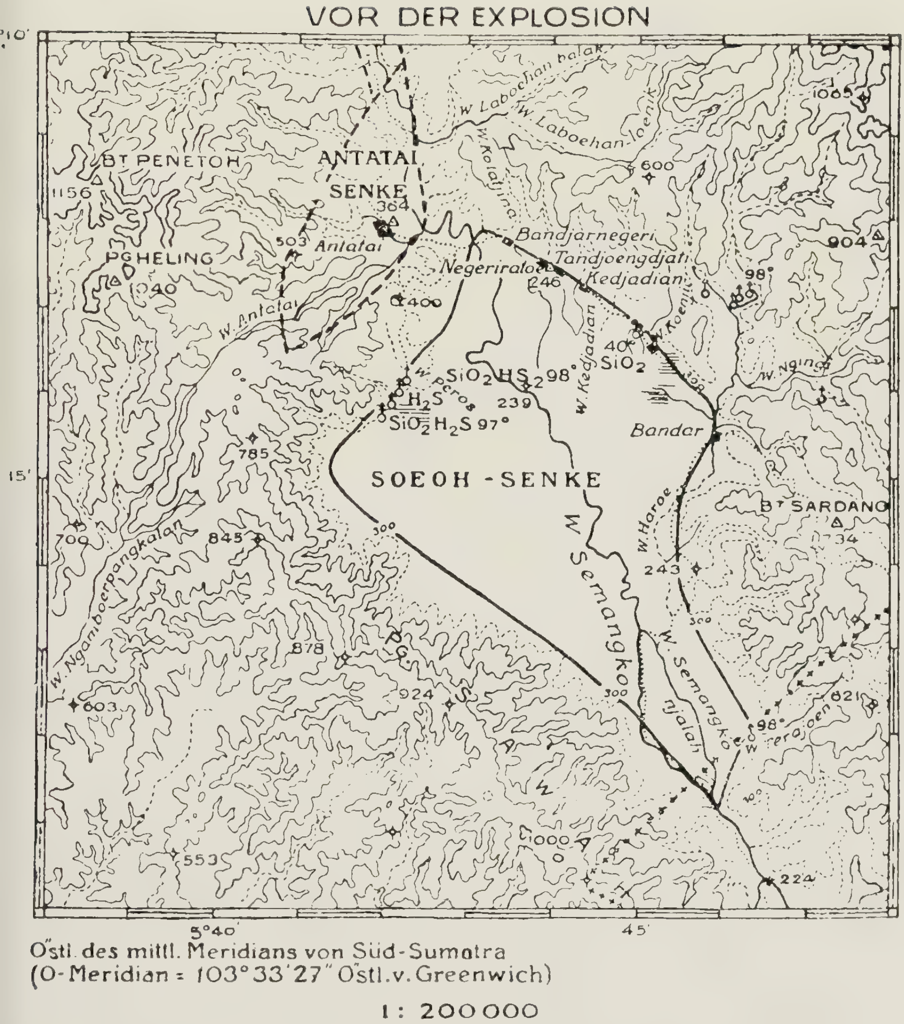


Fig. 1. — Carte de la dépression volcano-tectonique de Soeoh avant l'éruption phréatique.

1. R. W. van Bemmelen : De tektonische structuur van Zuid-Sumatra, in verband met de aardbeving van 25 Juni 1933, pp. 7-14.

2. H. P. Berlage Jr.: De aardbeving in Zuid-Sumatra van 25 Juni 1933. Waarnemingen in het epicentrale gebied. pp. 15-36.

3. S. W. Visser: De aardbeving in Zuid-Sumatra op 25 Juni 1933. Microseismische gegevens. pp. 37-45.

4. Ch. E. Stehn: Die semivulkanischen Explosionen des Pamatang Bata in der *Soeoh-Senke* (Süd-Sumatra) im Jahre 1933, pp. 46-69.

500 personnes périrent dans ce tremblement de terre. La secousse fut sensible jusqu'en Java Centrale à 600 km. de l' épicentre. La pression des gaz dans les sources et dans les solfatares monta remarquablement 13 heures après le tremblement, et ne cessa de s'accroître pendant 14 jours, jusqu'au moment où le 10 juillet, la vapeur d'eau se fraya un passage et forma 2 cratères. Entre le 16 et le 19 juillet, on compta plus de 100 ouvertures émettant de la vapeur, 7 parmi elles rejetaient de la boue et des pierres (fig. 2). La place où l'éruption eut lieu fut nommée **Pematang Bata**. 35 km² de terres furent dévastées ; la quantité de matières rejetées est évaluée par Stehn à 210.000.000 m³ et la profondeur du foyer d'explosion á 270 m. Suivant Stehn, la cause de l'éruption de vapeur est due au fait que de l'eau phréatique est entrée en contact avec du magma non refroidi, sous la plaine du Soeoh, transformant l' eau en vapeur. C' est donc ici un cas de très forte explosion phréatique (« phreatic eruption » ou « pseudo-volcanic eruption », Daly, 1914, p. 285) de même que l' éruption, en 1888, du Bandai-San (fig. 2 *a* et 2 *b*).

Outre d' innombrables éruptions phréatiques dans les champs de solfatares de Java, de moindre importance, on connait surtout les fortes éruptions de vapeur dans le cratère du Papandajan (1923-1925). Elles furent décrites par Taverne :

N. J. M. Taverne: De G. Papandajan, Vulkanologische berichten. No. XIV. Natuurkundig Tijdschrift v. Ned. Indië. LXXXI, pp. 102-137. Batavia 1925.

NACH DER EXPLOSION

Fig. 2. — Carte de la dépression volcano-tectonique de Soeoh après l'éruption phréatique

No. 21 Salak :

Des explosions de vapeur eurent lieu dans le champ de solfatares à l' ouest du Salak (No. 21) avec éruption de boue, probablement au début de fevrier 1935, jusqu' à

Fig. [illegible] [illegible] 17. VII. 1933

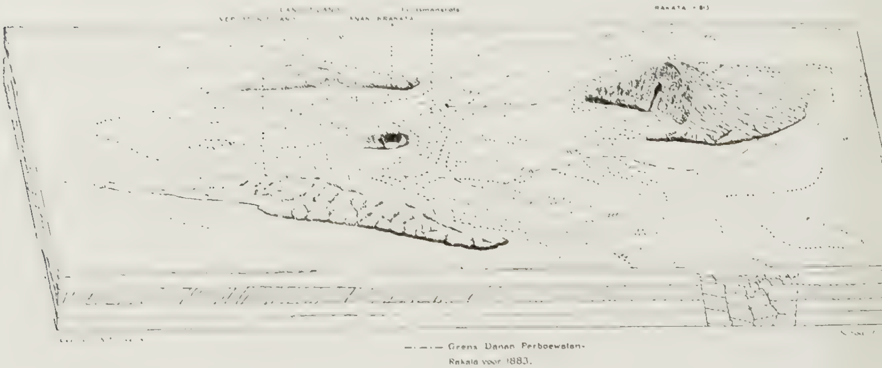
Fig. 2 *b* — Pematang Bata. VII. 1933.

(Phot Dr. S[illegible]IN)

500 m. du *Kawah Tjikaloewoeng*, et en mai ou au début de juin 1935, dans le *Kawah Tjibodas* (No. 22).

No. 18 Krakatau :

Le volcan qui demande ensuite notre attention est l'**Anak Krakatau** (No. 18), en éruption en 1933, 1934 et 1935 (fig. 3). On sait que la grande éruption du *Krakatau*, du 20 mai au 28 août 1883, se termina par la formation



Blokdiagram of the Krakatau-group.

Fig. 3. — Diagramme des Iles Krakatau.

d'une caldeira. Après un repos de 44 ans, une nouvelle éruption commenca le 29 décembre 1927, au milieu des îles Rakata, Verlaten Eiland et Lang Eiland, éruption qui eut lieu au bord de la caldeira d'effrondrement de 1883. Des éruptions sousmarines firent émerger une nouvelle île, l'*Anak Krakatau* (enfant de *Krakatau*), rongée par les vagues de l'océan Indien entrant le détroit de la Sonde. Les éruptions de cendre, de bombes et de lapille cessaient-elles, alors l'île devenait la proie des vagues et disparaissait quelque temps. Les savants ayant participé au quatrième « Pacific Science Congress », ont visité l'île de *Anak Krakatau* (II) en 1929, formée alors d'un reste du rim et portant diverses failles normales. Le diagramme ci-contre de M. Neumann de Padang (fig. 4) montre que l'*Anak Krakatau* I n'a existé que quelques jours, que II a per-

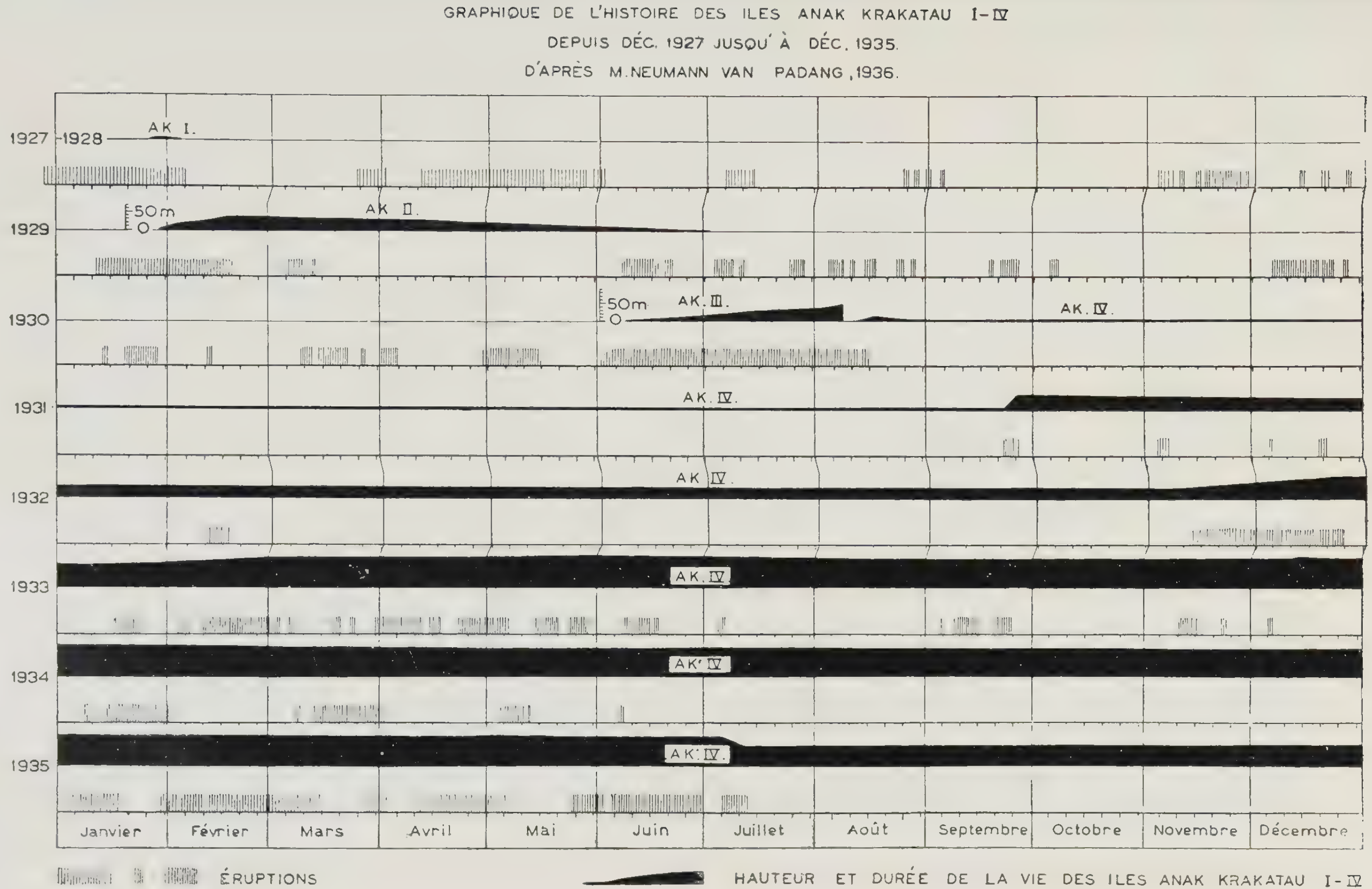


Fig. 4. Diagramme des Iles Anak Krakatau I à IV, et des périodes d'éruptions de déc. 1929 jusqu'à la fin de 1935.

sisté pendant 5 mois, III 2 mois et IV de juillet 1930 jusqu' après 1935.

L'*Anak Krakatau* est composée surtout de cendres. Des émissions de lave, telles qu' on les observa dans les Iles Kaimeni dans l'archipel de Santorin, n'eurent pas lieu ici. La cendre est de composition basaltique, avee 51 % - 55 % de SiO^2, et renferme de l' olivine, (le tuf ponceux de la grande éruption de 1883 contenait 60-70 % de SiO^2).

Les éruptions les plus violentes eurent lieu les 1 et 2 mai 1933, où les matériaux ignés furent projetés à plus de 2500 m. de hauteur et où la nuée de cendres atteignit 7900 m. (fig. 6 et 7). Suivant Neumann van Padang la quantité de matériaux projetés jusqu' au commencement de 1936 monte à 0,3 km^3, et la superficie de l' *Anak Krakatau*, y compris le cratère-lac, était de 1.55 km^2 (août 1935, fig. 8).

No. 31 Papandajan :

Ce cratère, constamment contrôlé par le séismographe vertical Wiechert, et par un enregistrement automatique de la température, ne présenta aucun phénomène important. En juillet 1933, une solfatare émit de la boue à souffre à 116°C. La température la plus élevée enregistrée fut de 410°C. (février 1934).

No. 41 Merapi :

Le Merapi (No. 41) en Java Centrale, fut très actif durant les années 1933, 1934 et 1935. Le dôme de lave du sommet provoqua de continuelles avalanches incandescentes et des nuées ardentes. De nuées volcaniennes firent pleuvoir sur la région environnante de la cendre et des bombes. Le 17 novembre 1934, de grandes nuées ardentes descendirent par le versant ouest dans le ravin du Senowo, parcourant 7 km. en 7 minutes, à la moyenne d'un km. à la minute ou 16,60 m. à la seconde ; elles étaient donc 10 fois plus lentes que la nuée ardente qui détruisit St. Pierre, le 8 mai 1902 (150 m. à la seconde). Un fait important est que le séismographe-Wiechert avait

Fig. 5. — Éruption à bombes de l'Anak Krakatau en Février 1929.
Photographie du dr. Neumans van Padang.

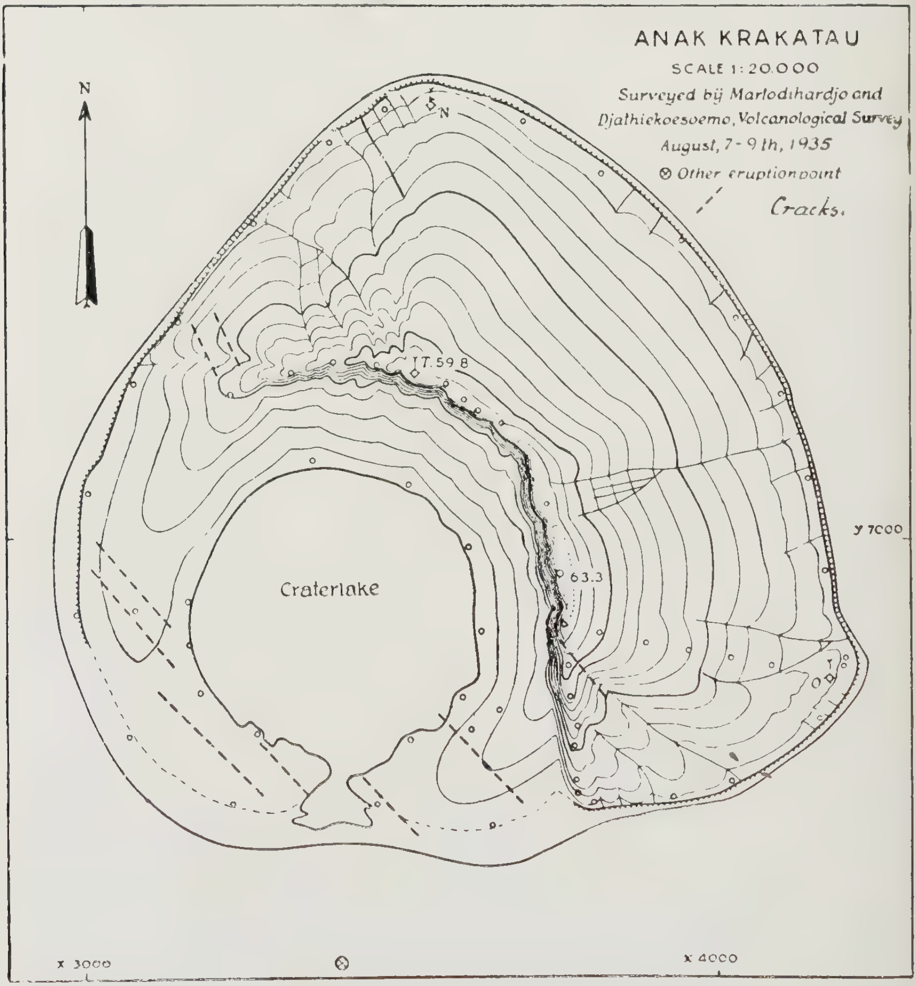
Fig. 6. — Éruption de l'Anak Krakatau du 1 Mai 1933.

Photographie du dr. STEHN.

Fig. 7. Éruption de l'Anak Krakatau pendant la nuit du 1 et 2 Mai [illegible] avec éclairs.

Photographie du dr [illegible].

enregistré 25 minutes plus tôt de forts troubles sismiques



State on August, 7—9th, 1935.

Fig. 8. — Carte de l'Anak Krakatau en Août 1935.

locaux ; les postes des Recherches Volcanologiques de Babadan et de Krindjing avertirent aussitôt la population

de la vallée du Senowo d'évacuer la région. Celle-ci fut couverte d'une couche de 10 à 20 mètres d'avalanches incandescentes et de nuées ardentes. Une large bande de terre le long du Senowo fut brûlée et dévastée par la pression de l'air. Grâce à la bonne organisation des Recherches volcanologiques, de nombreuses vies humaines furent sauvées. On ne compta pas de victimes. Après quelque temps, les pluies provoquèrent des explosions de vapeur dans les matériaux des avalanches incandescentes et des nuées ardentes. On releva en 1935 (janvier) 91 nuées ardentes. Entre le 1 déc. 1934 et le 11 janvier 1935, se produisit sur le sommet une faible coulée de lave.

Les observatoires de Babadan et de Krindjing possèdent tous deux des caves de secours et des appareils pour renouveler l'air. D'autre part, par mauvais temps (pluie et nuages), afin d'être

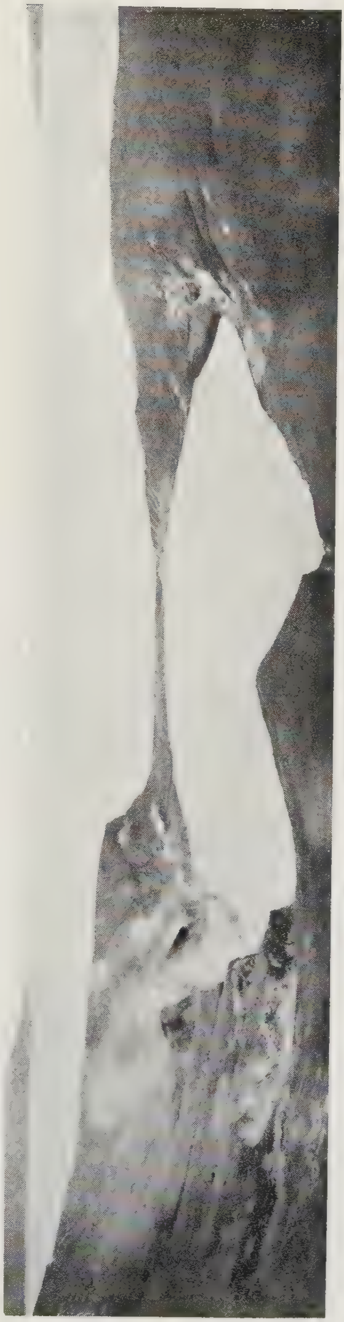


Fig. 9. — Cratère-lac de l'Anak Krakatau le 9 Avril 1934.
Photographie du dr. NEUMANN VAN PADANG.

averti si des nuées ardentes descendent dans la vallée du Senowo, on installa dans la vallée des appareils qui, par une température de plus de 50°, donnent l'alarme à l'observatoire de Babadan, par un coup sur un cadran numéroté. (Pour d'autres données concernant le Merapi, v. III).

No. 69 Lewotobi Lakilaki :

Le Lewotobi Lakilaki no. 69, dans l' Ile de Flores, fut actif. Le 10 janvier 1933, il lanca des bombes incandescentes. Le cumulovolcan gagna en hauteur et en diamètre ; il atteignait en février 1933 160 m. de hauteur, soit 40 m. au-dessous du sommet du volcan. Le 3 mai 1933 eut lieu un glissement d' une coulée de lave, parcourant 200 m. perdant ainsi le contact avec le dôme de lave.

No. 96 Doekono :

Dans l' île de Halmaheira commenca le 12 août 1933 une éruption du Doekono (no. 96). Chutes de cendres, explosions, coulée de lave, colonnes d'éruption de 2000 m. (1934) tels furent les phénomènes constatès. Le 12 août 1935, la coulée de lave atteignit une longueur de 3 km. Le ravin, large de 40 m. était comblé d' une couche de lave épaisse de 30 m.

III. Compte-rendu de quelques publications.

III^b *Du volcanisme aux Indes Néerlandaises en général.*

B. G. Escher considère (lit. 29, 30 et 35) le rapport existant entre le volcanisme dans les Indes-Néerlandaises et la région d'anomalie négative connue par les recherches sur la pesanteur de F. A. Vening Meinesz. Il cherche ce rapport en appliquant la théorie de A. Holmes à l'Archipel Indien. La région d' anomalie négative est sensée être formée d'une racine de matériel basaltique, tirée vers l' intérieur par des courants convergents, dans le substratum, tandis que le volcanisme est attribué à une tension dans l'écorce terrestre causée par un tourbillon horizontal dans le substratum.

Vening Meinesz (lit. 32) pense que les volcans des Indes Néerlandaises se trouvent entre autres à l' intérieur d'arcs où le mouvement de l'écorce terrestre de l' intérieur de l'arc vers la racine (« Buckling zone ») doit provoquer, dans le sens de la longueur, une tension, facilitant l' infiltration de magma dans l'écorce terrestre.

Ph. H. Kuenen (lit. 36) visita plusieurs volcans en qualité de géologue de l' expédition Snellius, tant actifs qu'en période de repos. Il examina au microscope diverses expèces de roches, tandis que M.le C. Koomans fit dix analyses chimiques. Dans la question de la caldeira du Tengger, la digue rectiligne, le Tjemoro Lawang, joue un rôle important. Kuenen en donne une nouvelle explication ainsi que de la formation des calderas du Tengger, en appliquant à ce volcan la « ring-dyke mechanism » des géologues écossais. La morphologie du Goenoeng Api au nord de Wetar est expliquée par de grands affaissements. Les roches examinées sont des basaltes à pyroxènes. On fit du Tidore cinq analyses, montrant des variations de SiO^2 de 50 à 70 %. Les roches varient du basalte basique à l'andésite acide. Un grand nombre de bons croquis de volcans en fixent la morphologie. Enfin l' auteur expose des considérations sur la pétrologie des volcans des Indes Néerlandaises.

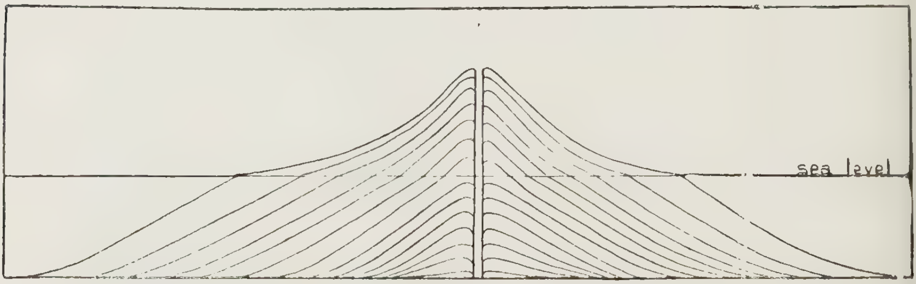
Dans lit. 37, Kuenen, se basant en partie sur les sondages à écho de l' expédition Snellius, donne entre autres une étude du talus sous-marin des volcans. Sa conclusion est que le talus sous-marin est à peu près droit, et plus raide que la partie inférieure du talus sec, qui est concave (fig. 10).

III^e *Des caldeiras et des depressions volcano-tectoniques.*

L'étude des caldeiras des Indes Néerlandaises a donné naissance à une bibliographie fournie, traitant surtout des monts du Tengger.

R. W. van Bemmelen classe les caldeiras parmi ses **dépressions volcano tectoniques**. L' auteur distingue comme tels (lit. 39) des formes intermédiaires entre le graben et

la caldeira d' effrondrement. Exemples de dépressions volcano-tectoniques à Sumatra : le lac Toba (1789 k2), le lac Ranau (106 km2) et le lac Manindjau (96 km2) auxquels VAN BEMMELEN ajoute, en Sumatra-Sud, une demi-douzaine de dépressions volcano-tectoniques, parmi lesquelles la dépression du SOEOH (Pematang Bata, no. 117).



Theoretical stages in the growth of a volcano from below sea level.

Fig. 10. — Coupe théorique de l'accroisement d'un volcan sous-marin d'après le dr. PH. H. KUENEN.

IIId *Des nuées ardentes du Merapi.*

KEMMERLING observa, pendant l'éruption du Merapi, en 1920, des nuées ardentes, d' où il conclut que les « nuées péléennes d'explosion dirigée », de LACROIX, n'existent pas mais qu'elles sont des « nuées ardentes d'avalanche », telles qu' il put les observer sur le Merapi. Nous nous sommes mêlés à ce débat (qui a donné naissance à une bibliographie assez riche), revenant encore sur la question après avoir vu deux tableaux du peintre javanais RADEN SALEH, représentant l' éruption du Merapi en 1885 (lit. 16). Suivant GRANDJEAN, les deux sortes de nuées ardentes furent observées sur le Merapi, celles qui prennent naissance des avalanches incandescentes et celles qui sont projetées obliquement vers le bas de la base du dôme. L'opinion de NEUMANN van PADANG (lit. 2 et lit. 15, pp. 80 93) différente de celle de GRANDJEAN, est que des nuées ardentes, projetées obliquement vers le bas n' ont pas été observées lors de l'éruption de 1930-1931, et que « l' explo-

sion initiale » de LACROIX était une explosion verticale, dirigée vers le haut.

Ch. E. STEHN étudia les nuées ardentes du Merapi durant les années 1933, 1934 et 1935, d'où résulte qu'il observa trois types de nuées ardentes : 1° **« Explosions glutwolken »** (NEUMANN van PADANG) =« nuée ardente d'explosion vulcanienne » (LACROIX) = « type St. Vincent » (ESCHER), du 1 octobre 1933 au 10 juillet 1934, donc pendant l'activité explosive du volcan ;

2° **« Absturzglutwolken »** (NEUMANN van PADANG) = « nuée ardente d'avalanche » (LACROIX) =« type Merapi » (ESCHER) pendant la phase conséquente d'effusion ;

3° du 6 au 21 avril et le 18 juin 1934 ; un type de nuées ardentes dont il écrit : « Der Glutwolkentypus nähert sich dadurch dem Pelée- typus ESCHER's, den LACROIX « nuée d'explosion dirigée » nannte ». Ce dernier phénomène a lieu quand le point d'explosion se fait à une certaine hauteur, dirigeant l'explosion non seulement verticalement mais encore latéralement. Ceci explique comment les produits explosifs purent se dégager vers l'ouest par la brèche du cratère, tandis qu'au nord, à l'est et au sud, ils rencontraient les parois du cratère, et par des tourbillons, grossissaient la quantité de matériel des nuées ardentes. Cette dernière étude de STEHN indiquerait que LACROIX a eu raison dès le commencement du débat.

III^e *Du volcanisme en général.*

Dans lit. 40, ESCHER réunit dans un schéma les principaux types d'éruptions centrales, faisant usage, pour la classification, de deux propriétés : la pression des gaz magmatiques et la viscosité des laves (fig. 13).

III^f *Volcanologie experimentale.*

Nous attirons ensuite l'attention sur les expériences très importantes faites par KUENEN (lit. 42) sur la formation des cônes volcaniques de petites dimensions, expériences dépassant celles de LINCK et d'autres. KUENEN

allongea ou raccourcit la longueur de la cheminée et fit varier la force des éruptions. Il réussit ainsi à obtenir des profils concaves, analogues aux profils naturels, et des cratères qui sont une bonne imitation des vrais cratères.

Nous reproduisons deux figures des nombreuses illustrations de KUENEN (fig. 11-12).

III^g *Des pluies d' éruption.*

NEUMANN van PADANG (lit. 43) rechercha dans les ouvrages publiés s' il est fait mention de pluies d' éruption, lors de la grande éruption du KRAKATAU de 1883. Suivant ces recherches, il n' y eut pas de pluie d'éruption, pas plus au KRAKATAU qu'au Merapi (18 au 19 décembre 1930). Dans une deuxième étude (lit. 44), la même question est étudiée à propos du SLAMAT (no. 36). La réponse fut encore négative. Durant les 10 éruptions du Slamat après 1926, il tomba moins de pluie qu'avant et après les éruptions. Les deux articles de NEUMANN van PADANG furent publiés comme suite à une remarque de M. A. HARTMANN, d'après laquelle il aurait plus lors d'une éruption de l'ANAK KRAKATAU en mai 1933. NEUMANN van PADANG attribue cette pluie aux éruptions à travers le cratère-lac ; la pluie consisterait donc en eau du lac. HARTMANN (lit. 45) discute ses observations faites lors de l' éruption du KRAKATAU (mai '33) et conclut que la pluie doit être attribuée surtout à la condensation de vapeur d' eau magmatique à faible altitude (jusqu' à 2000 m.), dans la zône des plus fortes pluies de cendre. Suivant HARTMANN, il y aurait eu également des pluies en 1933 et en 1934 lors de l' éruption du Merapi, ajoutant pertinemment que la quantité et l' étendue des pluies était faible. NEUMANN van PADANG (lit. 46) combat l'opinion de HARTMANN, se basant sur le rapport qu' il établit, ajoutant qu' il est impossible d'observer si des pluies naissent d'une nuée d'éruption comme celle de l'ANAK KRAKATAU (voir notre fig. 7), par condensation de la vapeur d'eau. La pluie du 10 juillet 1934 sur

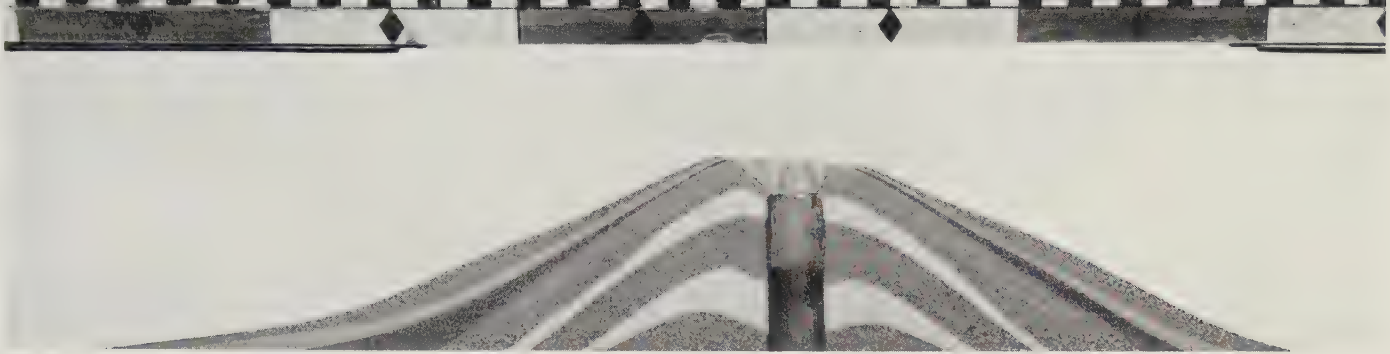


Fig. 11. — Coupe d'un strato-volcan expérimental d'après le dr. Ph. H. Kuenen.

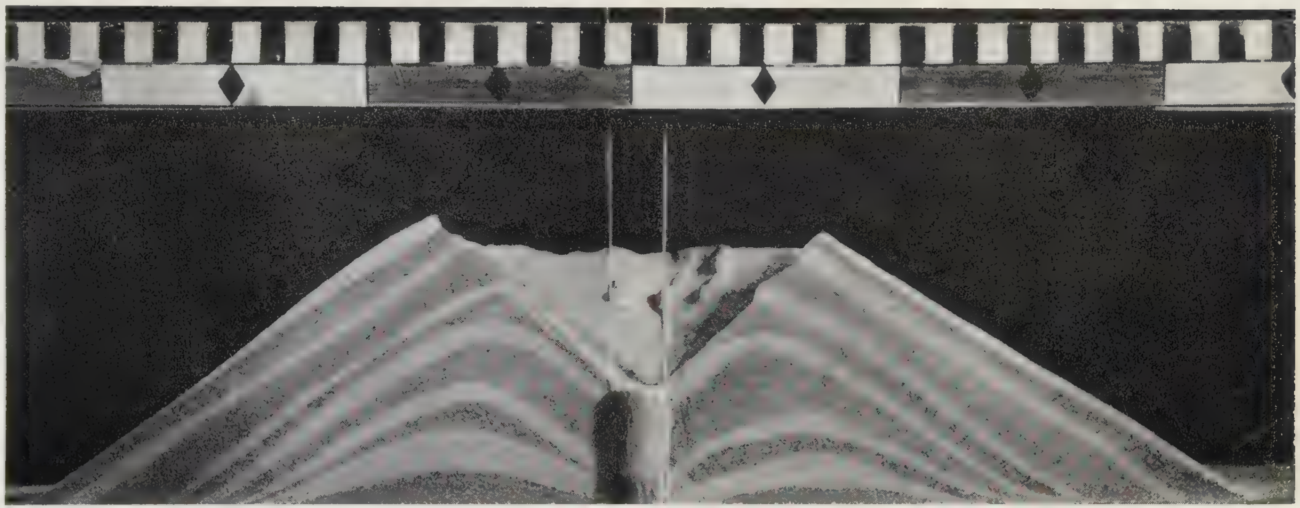


Fig. 12. — Coupe d'un strato-volcan expérimental d'après le dr. Ph. H. Kuenen.

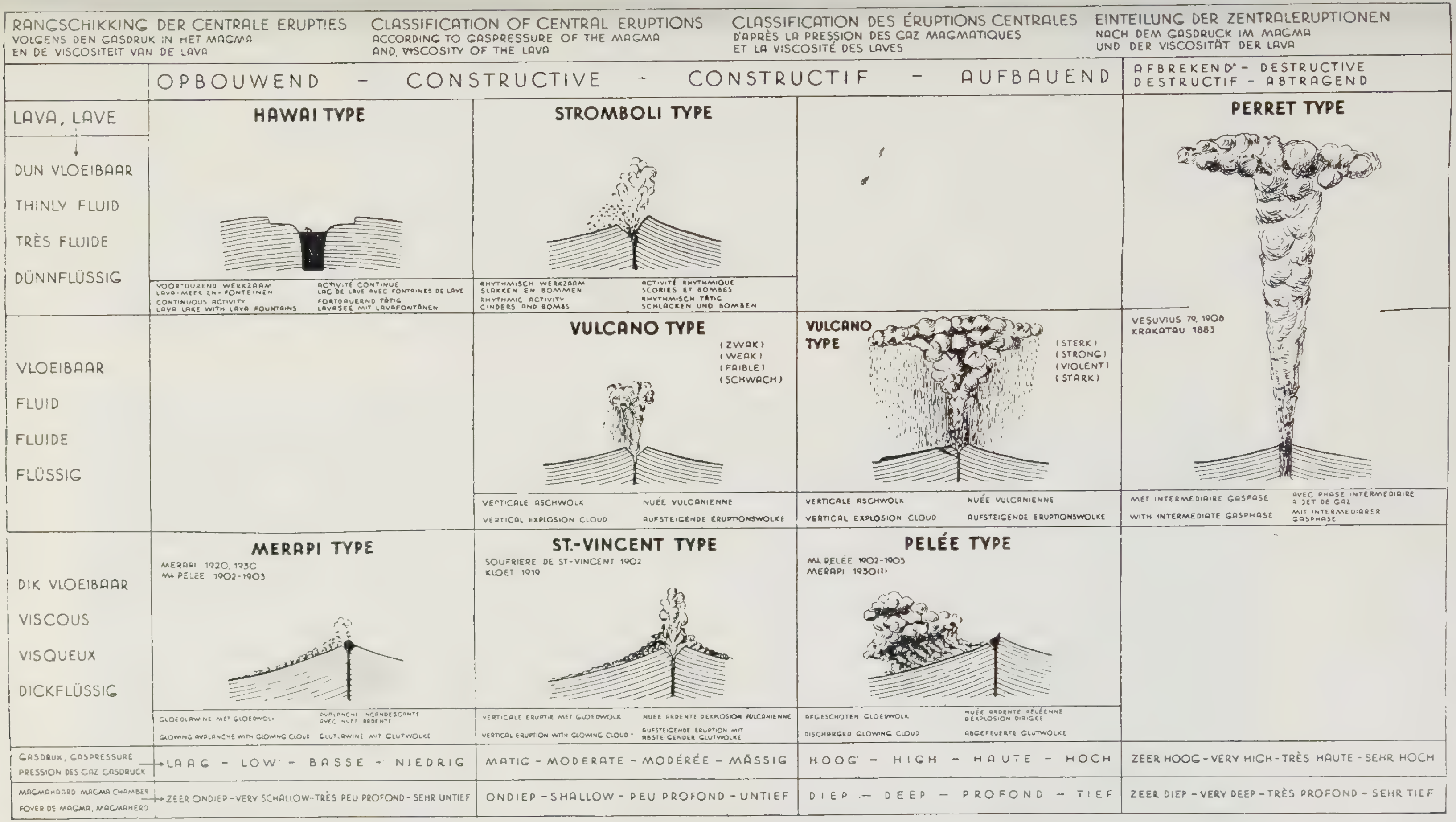


Fig. 13. — Classification des éruptions centrales d'après la pression des gaz magmatiques et la viscosité des laves d'après B. G. Escher

le versant du MERAPI n' était suivant NEUMANN van PADANG, qu'une pluie normale. Finalement HARTMANN (lit. 47), maintient sa première opinion.

IIIj *Publications traitant de quelques volcans*

1. **Merapi (No. 41)**

On a consacré quelques études importantes au MERAPI (Java Centrale), déja traitées en partie ici. M. A. HARTMANN a reconstitué, dans une série d'études, l' histoire du volcan, traitant d' abord, en lit. 19, les plus anciennes données historiques et ensuite l'état du volcan en 1786, 1797, 1807, 1810, 1812-1813, 1820, 1822-23, 1832-1836, 1837-1838, 1840, 1846-1847, 1848 ?, 1849, 1860-1870, 1872, (grande éruption), 1878-1879 et 1883. Il distingue 4 types d' éruption du MERAPI ; avec augmentation de la teneur en gaz du magma. Le type A est le plus pauvre en gaz, le type D est le plus riche. Dans le type A, des avalanches incandescentes et des nuées ardentes proviennent du dôme de lave (1883-1885 et 1909-1918) ; le type B est accompagné de lave visqueuse (première phase) et d'éruptions du type St. Vincent, avec avalanches incandescentes et nuées ardentes. Ce type est, suivant HARTMANN, le type d' éruption le plus commun du MERAPI ; il apparut en 1862-1869, 1887-1889, 1891-1894, 1902-1908, 1920-1923, 1930-1031. Le type C ressemble au type B, mais est plus violent : éruptions du type St. Vincent, accompagnées de nuées ardentes ; des explosions causent la formation d' un cratère ; (1832-1836, 1837-1838, 1846-1847, 1878 ?, 1879 ? , 1933-1935). Le type D commence par des éruptions du type St. Vincent, et passe alors au type PERRET (Vésuve 1906). Le sommet du volcan est enlevé ; 1822-1823, 1849, 1872).

Dans lit. 17, HARTMANN traite la grande éruption de 1872, sur laquelle n' étaient publiées que quelques données. La phase vulcanienne dura 120 heures, 200 personnes périrent. Le sommet du volcan ne fut atteint qu'en 1880 par FENNEMA, qui trouva un cratère profond à base

plate. HARTMANN juge qu'il avait 600 m. de long, 480 m. de large et 500 m. de profondeur. Le Mesdjidanlama (2727 m.) d'aujourd'hui est un reste du bord du cratère de 1872. Il n'y eut pas d'épanchement de lave, en 1872. Le 16 et le 17 avril, l'éruption atteignit son paroxysme, que HARTMANN compare à « l'intermediary gasphase » de PERRET (Vésuve 1906).

Dans lit. 18 HARTMANN traite l'activité du MERAPI dans la région-est de ses sommets de 1902 à 1908, période sur laquelle nous ne possédons que peu de données, A son avis, de même qu'en 1930, après une période de croissance du dôme de lave, des explosions de gaz frappèrent des brèches dans le dôme, phénomène accompagné de nuées ardentes, et l'éruption se termina par la formation d'une courte coulée de lave (1300 m. de long). Les nuées ardentes se frayèrent en 1904 et en 1907 un chemin vers le sud-est, par la vallée du Woro, causant la perte de vies humaines. En 1822-1823, en 1846 et en 1872 des nuées ardentes descendirent du même versant. Selon HARTMANN il est probable que des nuées ardentes descendront encore les versants est et sud du MERAPI.

NEUMANN van PADANG traite dans une monographie (lit. 2) l'importante éruption du MERAPI en 1930-1931, qui fit 1369 victimes. Ceci est du au fait que notre connaissance de l'importance des éruptions était autrefois trop petite. Les villages situés sur les hauteurs purent être évacués à temps, mais personne ne soupçonna que les nuées ardentes pousseraient jusqu'aux villages situés plus bas. Le 18 décembre 1930, elles descendirent jusqu'à 8 km. du sommet, celles du 19 décembre 1930, à 13 km.; les premières atteignirent l'isohypse de 800 m., les dernières la courbe de niveau de 500 m., alors que la brèche par laquelle s'échappaient les nuées ardentes se trouvait à 2700 m. d'altitude environ (fig. 14). La vitesse atteinte par ces nuées nous est malheureusement inconnue Celle d'une petite nuée ardente du 4 mai 1931 est évaluée à 75 m. par seconde (NEUMANN van PADANG). La température des fumerolles au sommet du MERAPI a été mesurée

de temps à autre depuis 1924, travail nécessitant souvent l'emploi des masques à gaz. Le résultat de ces recherches est que, quand la température des champs de fumerolles atteint en quelque endroit 600° C, il peut mais ne doit pas, s' ensuivre une éruption. Les séismes furent enregistrés depuis février 1924 par un séismographe Bosch-Omori, avec une composante Est-Ouest, à Maron. La direction appareil-sommet du volcan formait avec la direction Est-Ouest un angle de 35°.

En 1930 on enregistra un grand nombre de tremblements. L'agitation du sol reprit et s' accrut en juillet et en août 1930. Dès le 21 novembre 1930, les tremblements devinrent plus violents ; ils précédèrent l' émission de laves incandescentes au flanc du volcan, à une hauteur de 2400-2700 m., observées pour la première fois le 25 novembre 1930. Cette lave forma un dôme qui s' ébrécha et causa des avalanches de lave. L'émission lente de lave visqueuse à faible pression de gaz dura jusqu'au 18 décembre 1930. On évalue la quantité de lave écoulée alors à 6.000.000 m^3. De grands quartiers de roche furent précipités d'en haut (4 × 5 × 6 m), qu'on s'apercut être de l'andésite à hypersthène.

Le paroxysme fut atteint les 18 et 19 décembre 1930. Une brèche fut frappée dans la paroi ouest du sommet, sur une largeur de 200 m. et une longueur de 1350 m., allant jusqu' à 2150 m. Les anciens dômes de lave disparurent presque tous. Les premières grandes avalanches incandescentes, suivies d' une nuée ardente apparurent à 8^h08, 8^h27, 8^h50 et 8^h53, le 18 décembre, dans le ravin du Blongkeng, jusqu' à 6 km. du sommet et jusqu' à l' isohypse de 1000 m. La cendre tomba à Djocjakarta, à 30 km. au sud du sommet du volcan. A 11^h suivit une nuée ardente qui atteignit jusqu' à 8 km. du sommet et descendit à 800 m., tuant 17 personnes. Les villages supérieurs avaient été évacués. L'observatoire de Maron, du Service Volcanologique à une hauteur de 1000 m. environ, au sud du ravin du Blongkeng, déjà évacué, fut de nouveau visité dans l'après-midi. On y laissa quelques hom-

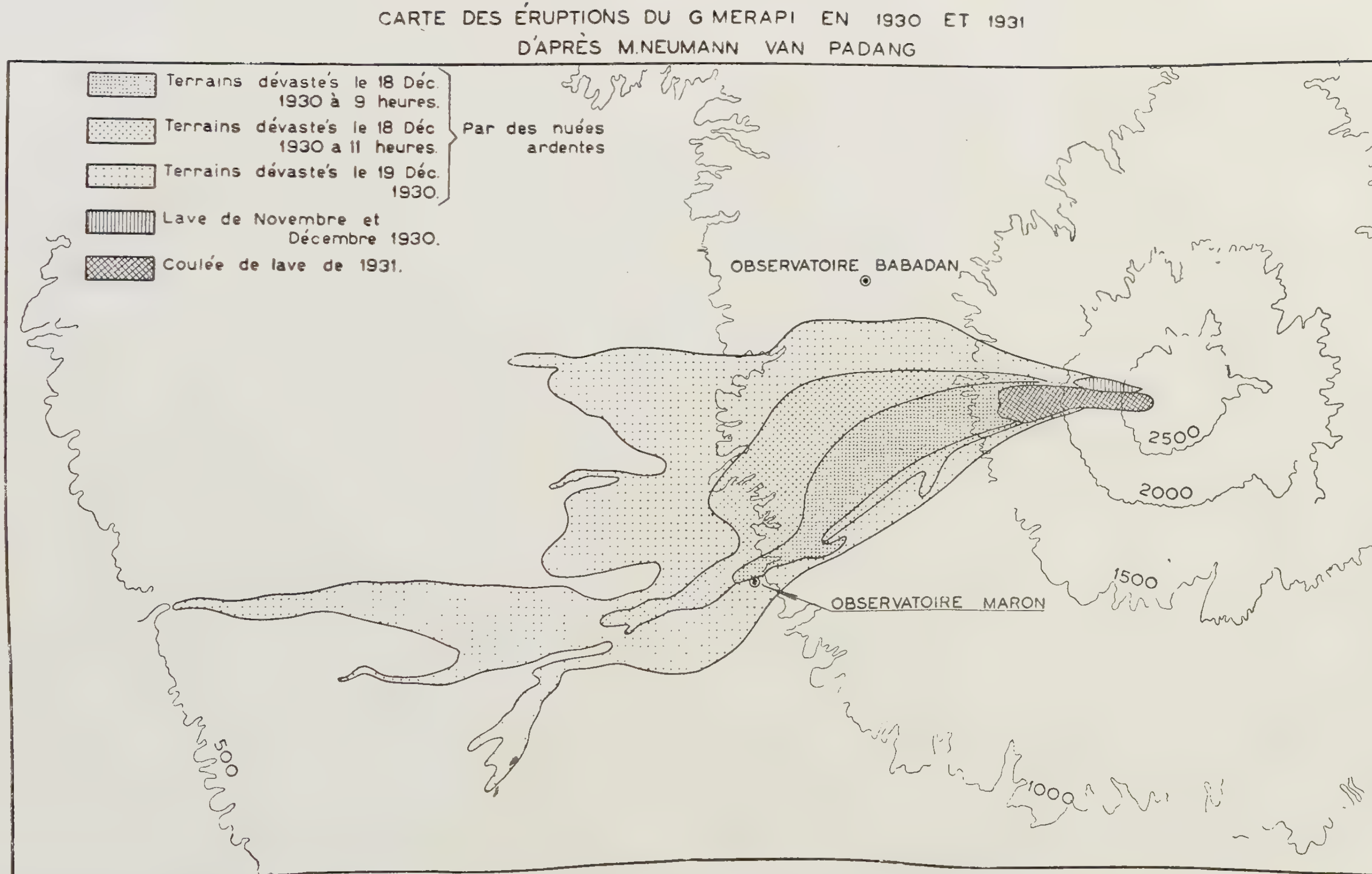


Fig. 14. — Carte du Mérapi avec extensions des produits des nuées ardentes du 18 et 19 décembre 1930.

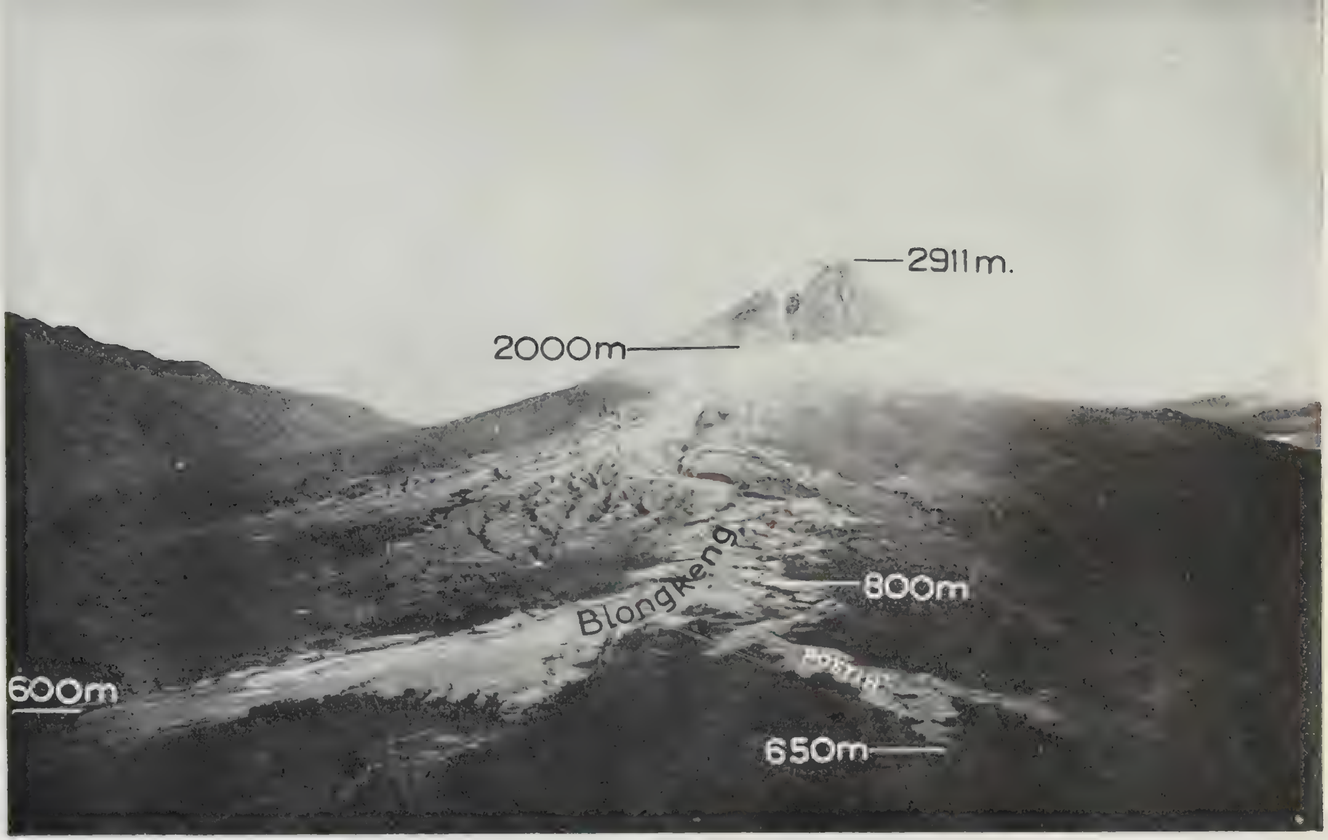


Fig. 14 *a*. — Le Mérapi de l'ouest, vu d'un avion à 3000 m. d'altitude, avec les terrains dévastés par des avalanches incandescentes dans les vallées du Blongkeng et du Poetih, et par des nuées ardentes. Décembre 1930.

Photogr. de l'aviation militaire. Bandoeng.

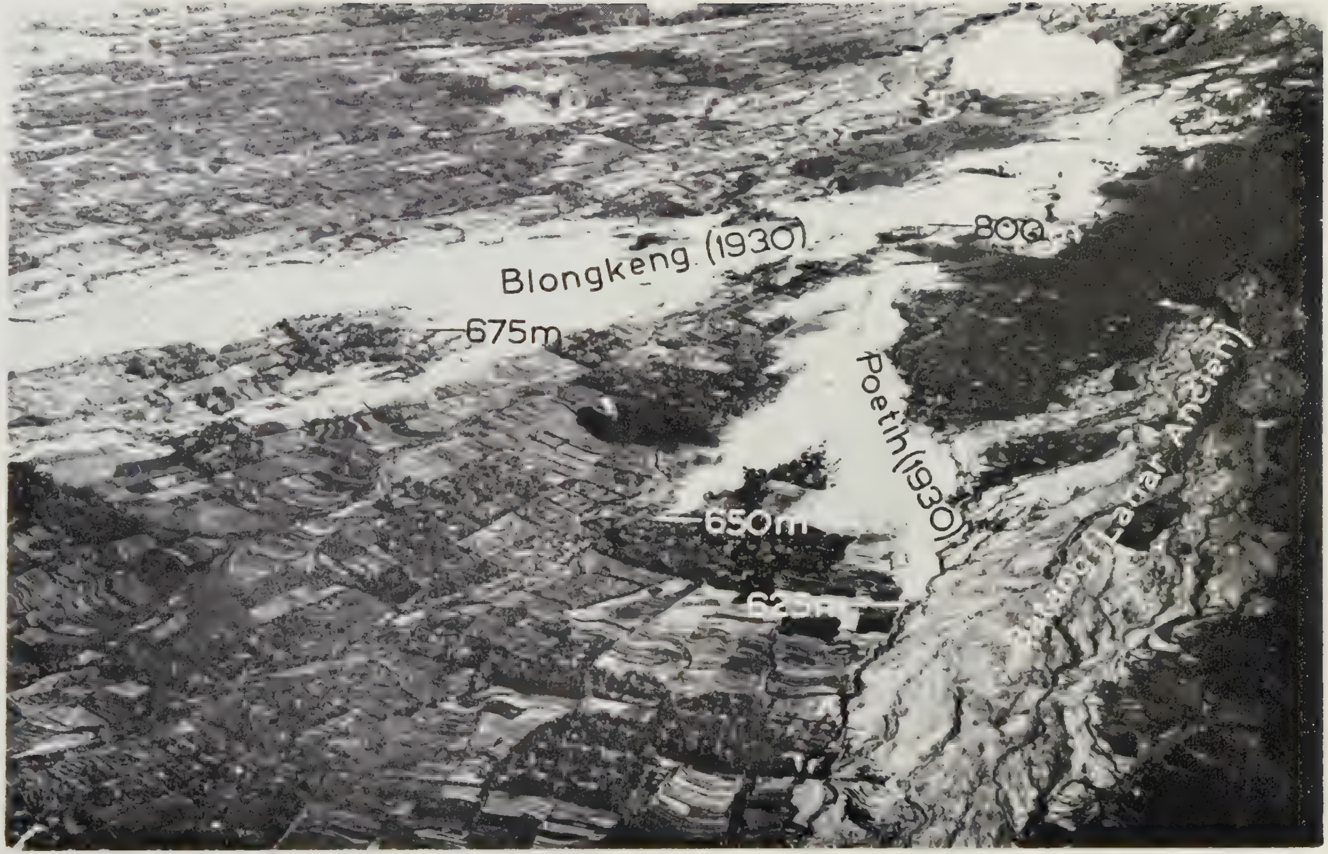


Fig. 144. — Le Mérapi. Les parties inférieures des vallées du Blongkeng et du Poetih avec produits des avalanches incandescentes et des nuées ardentes du 19 Décembre 1930, 21 Décembre 1931.

Photogr. de l'aviation militaire, Bandoeng.

Fig. 14 *c*. — Descente d'une petite avalanche incandescente, partant du dôme dans le cratère égneulé du Mérapi. 24 Décembre 1930.

Photogr. de l'aviation militaire, Bandoeng.

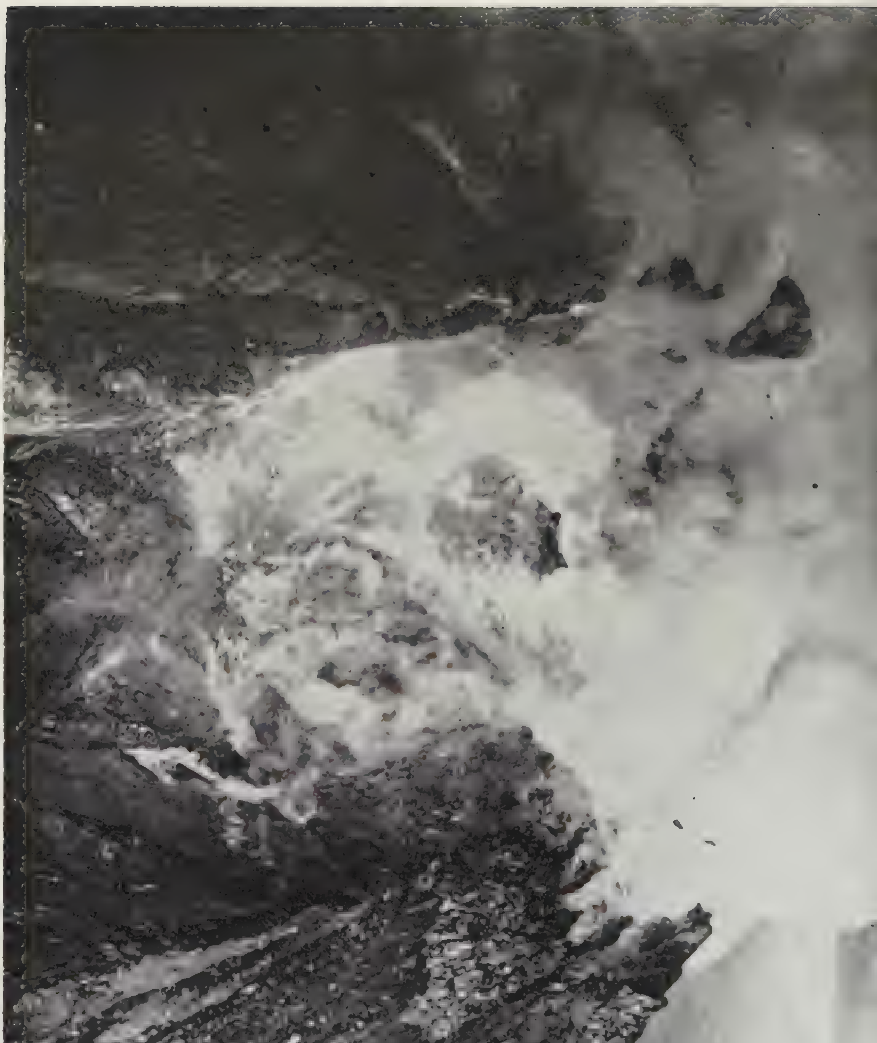


Fig. 14 *d.* — Le cratère égueulé du Mérapi avec dôme actif. Décembre 1930.

Photogr. de l'aviation militaire Bandoeng.

mes du personnel. Le 19 décembre, une grande avalanche incandescente survint, à 11h20, avec nuée ardente, depassant l'observatoire. Le personnel avait heureusement délaissé le poste. Les grandes avalanches incandescentes qui descendirent le 19 décembre 1930 dans le ravin du Blong-

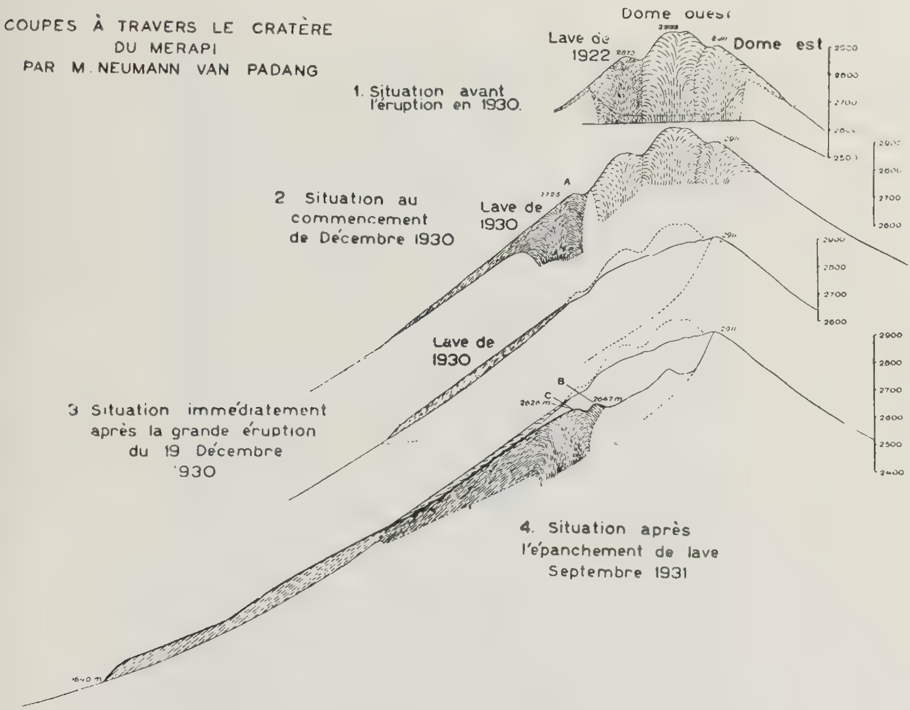


Fig. 15. — Coupes par le cratère du Mérapi.

keng, accompagnées de nuée ardentes (dévastant une large région des deux côtés du ravin), détruisirent entièrement 13 villages et en partie 20 autres, et rasèrent l'observatoire de Maron. Après le paroxysme il se forma un nouveau dôme dans la brèche, avec formation de petites avalanches incandescentes ; cette activité dura jusqu'au 6 mars 1931. Le 9, un épanchement de lave se forma au pied du dôme, s'allongeant lentement durant les journées suivantes, descendu en septembre 1931 jusqu'à 1640 m., alors que le sommet du dôme se trouvait à 2626 m. Le

volume de la coulée de lave est évalué à 36.000.000 m³. Ensuite l'activité du volcan diminua peu à peu jusqu' à la fin de 1931 (fig. 15).

La quantité de magma rejetée est évaluée par Neumann van Padang à 43.000.000 m³. La lave est, de même

Fig. 16. — Entrée du tunnel de l'Observatoire du Mérapi à Babadan.
Photographie du dr. Neumann van Padang

que dans les éruptions précédentes du Merapi, de l' andésite vitreuse à augite et hypersthène avec hornblende, à 55 % de SiO_2. Comme il se passe ordinairement dans les Indes Néerlandaises, l' éruption fut suivie de coulées de

boue, (« lahar' s »), qui causa de grands dommages détruisant des routes, des ponts et couvrant les champs de sable. Elles sont la suite des pluies tropicales sur la grande quantitè de matériel meuble.

On construisit un nouvel observatoire, à Babadan (pourvu d'un tunnel de secours ayant un volume de 66 m^3) au nord de la région dévastée de la vallée du Senowo, à 1279 m. de hauteur à 4 km. du sommet. Dans le tunnel est placé un séismographe (fig. 16).

Enfin, nous attirons l'attention sur l'étude de M. Hartmann (lit. 20) traitant l' éruption de la deuxième moitié de 1934 où le point d'éruption fut déplacé vers l'est avec formation d' un nouveau dôme de lave.

Nous renvoyons pour d' autres détails du Merapi au chapitre II.

2. **Raoeng** (No. 51).

J. J. Richard (lit. 22) parvint le premier, en frayant un chemin, à descendre dans le cratère du Raoeng. Le sommet du cratère se trouve à 3330 m. de hauteur, le fond du cratère mesure 2100 m. sur 1700 m., et est à 500 m. du bord. Ce cratère doit être compté parmi les caldeiras quant à ses dimensions et sa morphologie. Dans la caldeira se dresse un cône, élevé durant les 30 dernières années, depuis 1902. Il est curieux que cette caldeira ait été formé au flanc d' un ancien volcan, le Goenoeng Wates (fig. 17).

M.lle C. Koomans analysa 9 roches du Raoeng ; elles sont du magma tonalitique au dioritique normal de Niggli, et se composent de basaltes et d'andésites, à 52-59 % de SiO^2.

3. **Batoe Tara** (No. 75) = (Komba).

M. Hartmann (lit. 24) visita cette île volcanique en 1931 ou en 1932. Le volcan a un cratère égueulé actif et un petit cratère en forme d' entonnoir, inactif. Le type d' éruption est strombolien avec épanchements de lave. Lors de cette expédition, une dizaine de grandes solfa

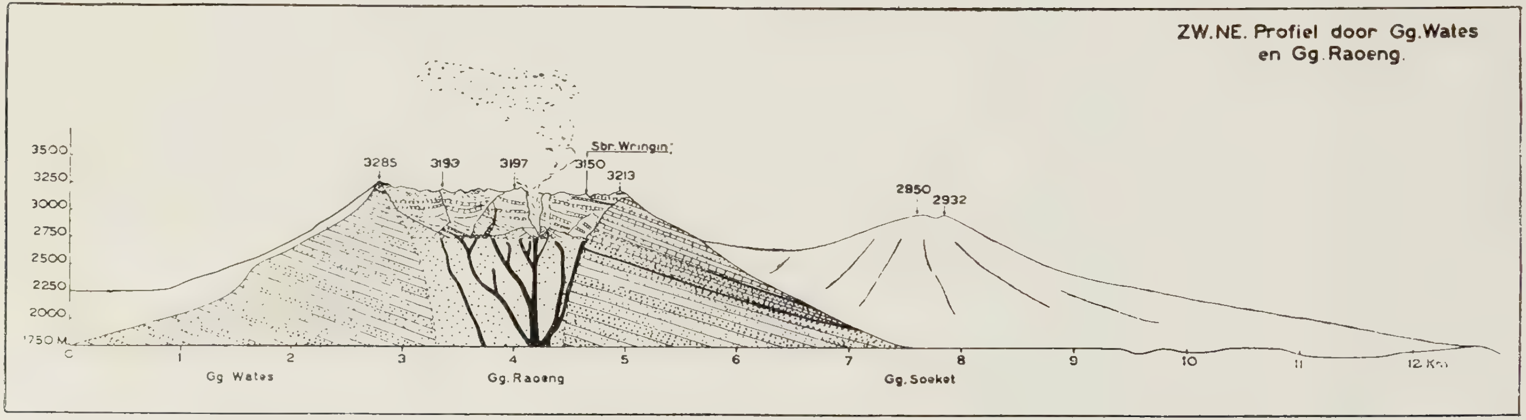


Fig. 17. — Coupe par le Gn. Raoeng par M. J. J. Richard.

tares émettaient du soufre ; Hartmann est d'avis que la phase solfatarienne dure depuis 40 ans [1]). Hartmann décrit 9 espèces de roches du Batoe Tara ; ce sont des basanites à leucite, des basaltes à leucite et des leucitites. Le Batoe Tara est un des seuls volcans actifs, ou le seul, des Indes Néerlandaises, qui soit formé de roches leucitiques.

4. **Siroeng** (No. 76).

M. A. Hartmann a visité en novembre 1931 le Siroeng, volcan peu connu au Sud de l'île de Pantar. Dans le massif du Siroeng se trouve une caldeira de 2000 à 2500 m. diametre caractérisé par deux niveaux.

La caldeira inférieure, à base plate, se trouve à 360-370 m. au-dessus du niveau de la mer. Autour de cette caldeira, à 500 m. se trouvent 5 cratères (restes d'une grande caldeira ancienne ?). Le bord de la caldeira compte des sommets de 742, 748, 794 et 862 m. La caldeira inférieure s'est formée par effondrement, a 2 km. de long sur 1,5 km. de large et une profondeur moyenne de 200 m.

Le fond de la caldeira se compose de boue à soufre et est le fond d'un cratère-lac disparu en 1921. Il reste 5 petits lacs, remplis d'une eau acide , vert-brun ou jaune-brun. Aux environs des lacs se trouvent des solfatares. On nota, dans un autre groupe de solfatares une température de 320°C. Enfin, il se trouve dans la caldeira un petit cône volcanique de 80 m. de diamètre, accompagné de solfatares. Les roches collectionnées sont des basaltes et des andésites.

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[1]) Le rapporteur fit le 11 avril 1919 le tour du Batoe Tara, et put observer du bateau, dans le cratère égueulé un grand nombre de solfatares d'où s'écoulait du soufre jusqu'à la côte, où des indigènes d'une autre île la recueillaient par grands paquets.

PLACES WITH VOLCANIC ACTIVITY IN THE NETHERLANDS INDIES
• Volcanoes with magmaeruptions or periods of increased activity later than the year 1600.
○ Volcanoes in fumarolic stage, no magma-eruptions known after the year 1600.
+ Solfatara-or fumarole fields.
MALACCA
SUMATRA
SOUTH CHINA SEA
BORNEO
JAVA
INDIAN OCEAN
CELEBES SEA
SANGIHE
MINDANAO
HALMAHEIRA
PACIFIC OCEAN
CELEBES
BOEROE
CERAM
NEW GUINEA
BANDA SEA
FLORES
WETAR
TIMOR
SOEMBA
AUSTRALIA
Scale 1:10.000.000

F. SIGNORE
R. UNIVERSITÀ DI NAPOLI

Rapporto riassuntivo sull'attività vulcanica nel Golfo di Napoli durante il triennio 1933-1936

La zona vulcanica partenopea, come è noto, comprende i tre gruppi vulcanici: Isole flegree (Ischia, Procida e Vivara), Campi flegrei, Vesuvio.

Le Isole flegree sono costituite in prevalenza da materiale frammentario trachitico basico, salvo Vivara che contiene, sempre sotto forma frammentaria, un magma basaltico. L'Isola d'Ischia è però abbastanza ricca di correnti laviche.

I Campi flegrei si estendono dalla spiaggia di Cuma e di Miseno al fiumicello Sebeto. Essi sono costituiti da materiali frammentari e da rare colate laviche. I materiali, sotto qualunque forma si presentino, sono di natura trachitica basica con il 54-58 % di silice. Solo al lago d'Averno sotto forma frammentaria si trova un magma leucitico, che, in base al suo contenuto in sanidino, è considerato da ZAMBONINI e CAROBBI, dal punto di vista chimico, affine a molte *vicose* della regione comagmatica romana e detto perciò *vicoite.*

Il Somma-Vesuvio, vulcano composito a recinto, ha eruttato invece costantemente materiale leucotefritico.

Dei tre gruppi in parola, mentre il Vesuvio è in piena attività effusiva ed esplosiva, i Campi flegrei e le Isole flegrei sono quiescenti.

Il Vesuvio dopo l'eruzione del giugno 1929 entrò nella fase fumarolica o, come si suol dire, solfatarica, che fu interrotta nei mesi di settembre e novembre 1929, da lievi esplosioni miste. Nei primi mesi del 1930 ebbe una energica ripresa di attività esplosiva e dal 7 luglio al 15 agosto dette un abbondante efflusso lavico, che si riversò nel cratere.

Terminato questo periodo di attività alla bocca del

vulcano non si notarono che scarsissimi fumi e a lunghi intervalli qualche debole lancio di materiale incandescente. Durante gli anni 1931-32 il vulcano cadde in completo riposo: ogni traccia di incandescenza e di bagliore scomparve alla bocca. Da uno scandaglio fatto nel settembre 1932 risultò che il condotto vulcanico era libero fino alla profondità di 320 m. circa.

Il 25 gennaio 1933 agli apparecchi sismici dell'Osservatorio Vesuviano fu registrata una lievissima scossa, che fu seguita alla distanza di otto giorni, dal 2 al 4 febbraio, da circa 1200 scosse, di intensità variabile tra il II e il VI grado Mercalli, i cui epicentri erano situati fra 1° 55′ e 2° 1′ di longitudine E. di Roma e tra 40° 44′ e 40° 48′ di latitudine N. (Carta del Vesuvio. Scala 1 : 25000; levata 1900, aggiornata a tutto il novembre 1929).

La zona epicentrale sopra delimitata, facente parte delle vecchie formazioni del Monte Somma, racchiude le bocche eccentriche del 1760, del 1794, del 1861 e quelle, di epoca ignota, del Viulo, del Fosso Monaca e dei Camaldoli della Torre.

Questa teoria di scosse deve considerarsi come inizio della nuova attività del Vesuvio.

Le lave tentarono in un primo momento di aprirsi la strada attraverso le pendici meridionali del Monte Somma, ma non riuscendo a rompere lo spesso mantello di vecchie lave, si incamminarono nell' antico condotto, sgorgando, dopo quattro mesi, il 3 giugno 1933, da un fontanile apertosi nel cratere alla base SW del conetto eruttivo.

Le lave, invase la metà orientale del cratere, si riversarono sui fianchi del Gran Cono avviandosi nella Valle dell' Inferno.

L' efflusso lavico, cominciato il 3 giugno 1933, salvo alcuni periodi di pausa, continua tuttora ad elevare il fondo craterico o a riversarsi nella Valle dell' Inferno.

La lava, che all'inizio dell'efflusso era molto viscosa, è andata man mano acquistando una notevole fluidità; in parecchi cunicoli ho avuto varie volte occasione di osservare correnti con velocità di circa due metri al secondo.

La temperatura della lava si mantiene intorno ai 1200°C.

L' attuale fase vesuviana è prevalentemente effusiva: in tutto il triennio solo poche volte l' attività esplosiva è stata abbastanza intensa.

Le ricerche gravimetriche eseguite alle falde del vulcano negli anni 1934-35, sotto la direzione del Sen. Prof. Soler, hanno messo in evidenza una notevole deficienza di densità tra Trecase e Boscoreale, cioè nella zona ove, nel 1933, si ebbe la massima intensità sismica.

Una livellazione di precisione sarebbe stata molto utile poichè avrebbe potuto dirci se nella medesima località si verificano anche delle variazioni di livello.

Nel triennio in parola anche i Campi flegrei hanno presentato un notevole aumento di attività.

Si sono notati con molta frequenza in varî punti della spiaggia fra Pozzuoli e le Stufe di Nerone rapidi aumenti di temperatura nella sabbia e nell'acqua del mare. Aumenti di temperatura si sono riscontrati nelle acque dei varî pozzi termominerali dei dintorni di Bagnoli, nelle sorgenti delle Terme di Agnano e al Rione delle Mofete.

La temperatura della Solfatara di Pozzuoli nel 1935 ha raggiunto un valore molto alto: da 175°,5 trovati nel luglio 1927 si passò nel gennaio 1935 a oltre 215°. Contemporaneamente all'aumento di temperatura si ebbe l' apertura di una nuova bocca nel piano del lago.

La comparsa di nuove bocche è divenuta molto frequente in questi ultimi tempi, e ciò, come ho dimostrato in un recente lavoro, sta in relazione con l' aumento continuo dell'attività vulcanica.

La ripresa di attività nei Campi flegrei dovette incominciare verso la fine del 1700 e da allora con *andamento discreto* è andata man mano aumentando.

Considerando le varie fasi attraversate dall' attività vulcanica e dal bradisismo flegreo, risulta chiaro che l'attuale incremento dell'attività vulcanica è in relazione con il rapido abbassarsi della zona e che le località maggiormente soggette al bradisismo sono quelle ove si riscontra la massima attività vulcanica.

CHRONIQUE DE L'UNION GÉODÉSIQUE ET GÉOPHYSIQUE INTERNATIONALE

International Union of Geodesy and Geophysics Sixth General Assembly: Edinburg, 1936. Association of Volcanology: Minutes

Joint Meeting of the Emergency Committee and the Volcanology Section Sub-Committee of the British National Committee.

The first meeting of these Committees took place on Thursday September 17 th. at 9.30 a. m., and lasted until 10.15 a. m.

Present :

Prof. A. Michel-Lévy, first Vice-President
Sir J. S. Flett, F. R. S., Chairman of Volcanology Section Sub-Committee of the British National Committee.
Dr. H. Jeffreys, F. R. S., Member of Volcanology Section Sub-Committee of the British National Committee.
Dr. J. E. Richey, Mr. A. G. MacGregor — Local Secretaries for Association of Volcanology
Brigadier Winterbotham, General Secretary of the Union.

1. Sir John Flett referred to the recent death of Dr. Bernard Smith, Director of the Geological Survey of Great Britain and a member of the Volcanological Section Sub-Committee of the British National Committee, and moved a vote of sympathy with his widow.
2. Dr. H. Jeffreys examined Sir John Flett's report on British Volcanological research 1933-1936, and signified his approval. The report was then handed over to the local secretaries.
3. Prof. Michel-Lévy handed over to the Emergency Committee a letter from Prof. Signore, Italy, Assistant Secretary of the Association, explaining his absence and giving an account of the work of the Internatio-

nal Central Bureau of Volcanology for the period 1933-1936. He also put on the table certain correspondence, a finacial statement, and accounts, handed over by Prof. Signore to Prof. Michel-Lévy in Paris.

First General Assembly of Association of Volcanology, Thursday, September 17 th. at 14.50.

Present :

Prof. A. Michel-Lévy, first Vice-President

Sir J. S. Flett, Chairman of Volcanology Section Sub-Committee of the British National Committee

Dr. Axel Gavelin, Delegate from Sveden

Dr. J. E. Richey Mr. A. G. MacGregor	Local Secretaries for Association of Volcanology
Dr. L. Hawkes Mr. D. Balsillie Dr. E. M. Anderson Dr. R. M. Craig	British Guests

1. Sir J. S. Flett opened the proceedings with words of welcome and introduced the first Vice-President, Prof. Michel-Lévy.
2. Prof. Michel-Lévy gave a brief address in which he touched on the lamented death of the President, Prof. Kténas of Greece, and gave a resumé of the events which led to his own presence in Edinburgh as first Vice-President, and to the absence of the Secretary (Prof. Malladra) and of the Assistant Secretary (Prof. Signore). He referred to his meeting with Prof. Signore in Paris when the latter handed over a report on the work of the Bureau, a statement of accounts, correspondence relating to the propositions for the Edinburgh Assembly, and a copy of the latest part of the Bulletin (published in August 1936). He referred to his pleasure at the reception of the Association in Edinburgh and to the work of Sir Archibald Geikie,
3. Prof. Michel-Lévy then read Prof. Signore's Report in full.

4. At the suggestion of the Vice-President the Local Secretaries, Dr. J. E. RICHEY and Mr. A. G. MACGREGOR, were authorised to act as temporary joint secretaries for the Association during the Edinburgh Assembly.
5. Prof. MICHEL-LÉVY explained that the programme for scientific propositions for the Edinburgh Meeting was largely due to the activity of the Volcanology Section of the British National Committee. He had brought a communication of his own and one on behalf of Prof. A. LACROIX. He appealed for further contributions for the Programme. Dr. A. GAVELIN agreed to deliver a short address. Dr. GAVELIN handed to the Acting Secretaries a Summary Report on the Researches in Sweden on Volcanic and Related Phenomena during 1933-1936.
6. Prof. MICHEL-LÉVY then read letters addressed to Prof. SIGNORE from (a) the Secretary of the International Association of Geodesy, and (b) Prof. G. C. GEORGALAS, Director of the Laboratory of Mineralogy and Petrology of the University of Athens. The first concerned the work of the Commission for the Study of the Earth's Crust ; the second intimated that Prof. GEORGALAS had succeeded to the chair of the late Prof. KTÉNAS. As Prof. GEORGALAS had only entered on his new duties he could not submit personal propositions for the Edinburgh Assembly, nor had he any from the Greek National Sub-Committee of Volcanology. Prof. KTÉNAS' researches on the Tertiary and Quaternary lavas of the Aegean Sea would be carried on by the Laboratory of the University of Athens. The same Laboratory would report annually on new phenomena relating to the active volcanoes of Greece. Sir JOHN FLETT moved a vote of thanks for these letters.
7. Dr. AXEL GAVELIN (Sweden) and Colonel AGOSTINHO (Portugal) were invited to study the accounts of the Association and the financial summary prepared by

Prof. SIGNORE, and to report on these to the Association before Sept. 24 th.

8. Names of those wishing to attend certain Local Excursions were taken by the Secretaries.

Informal Meeting, on Friday, September 18 th. at 9.30.

Present :

Prof. A MICHEL-LÉVY, first Vice-President

Sir J. S. FLETT	Chairman, Volcanological Section Sub-Committee of British National Committee.
Col. AGOSTINHO	Portugese Delegate
Dr. J. E. RICHEY Mr. A. G. MACGREGOR	Local Secretaries and Acting Temporary Secretaries of the Association.

Dr. A. GAVELIN (Swedish Delegate), Dr. A. L. DAY (U. S. A. Delegate) and Brigadier WINTERBOTHAM (General Secretary of the Union) were present part of the time.

All present fully understood the situation, and the proposals of the Vice-President, before leaving the Committee Room, and general agreement on policy was reached.

Saturday, September 19 th.

9.30 Informal Business Meeting.
Discussions took place between Sir J. S. FLETT and Prof. MICHEL-LÉVY and others on various topics concerning the election of new office-bearers.

10.00 Association Meeting. Prof. MICHEL-LÉVY presided. Dr. AXEL GAVELIN (Sweden) read a paper entitled « Summary Report of the Researches in Sweden on Volcanic and Related Phenomena during the Period 1933-1936 » .

Replying to a question by Dr. LEONARD HAWKES, Dr. GAVELIN said that volcanic glasses were not found in the Pre-Cambrian rocks of Sweden.

10.15 Prof. MICHEL-LÉVY, on behalf of Prof. A. LACROIX, gave a resumé of Prof. LACROIX's memoir entitled : « Le Volcan Actif de l' Ile de Réunion ».

10.30 Prof. MICHKL-LÉVY gave an account of experiments recently carried out by him with minute quantities of explosives. The subject was « Détonation des Explosifs et Explosions Volcaniques ».

Dr. HUBERT said a few words in appreciation of the importance of the applications to volcanology of the results of Prof. MICHEL-LÉVY's experiments.

Mr. A. G. MACGREGOR asked Prof. MICHEL-LÉVY to convey to Prof. LACROIX the thanks of the Association for bringing his important new memoir to its notice and for presenting a copy to the Library. He also joined with M. HUBERT in his appreciation of Prof. MICHEL-LÉVY's paper.

There were present :

Prof. MICHEL-LÉVY (Acting President)

Dr. J. E. RICHEY and A. G. MACGREGOR (Acting Secretaries)

Prof. DAHLBLOM, Dr. HUBERT, Sir J. S. FLETT, Prof. O. T. JONES, Dr. LEONARD HAWKES, and Mr. S. I. TOMKEIEFF.

The Meeting was adjourned at 11.0.

Afternoon. A number of the Association delegates including Prof. MICHEL-LÉVY, joined the Seismology Association excursion to the Ochil Fault.

Monday, September 21 st.

Second General Assembly of the Association of Volcanology.

Prof. A. MICHEL-LÉVY (France), Vice-President, took the chair. Acting Secretaries, Dr. J. E. RICHEY and Mr. A. G. MACGREGOR were present.

The following were present as delegates : Dr. A. L. Day (U. S. A.) ; Prof. B. Salamon (Czechoslovakia) ; Dr. H. Hubert (France) ; Sir J. S. Flett (Great Britain); Dr. S. W. Visser (Holland) ; Dr. A. Imamura (Japan) ; Lieut. G. Roux (Morocco); E. E. Janezewski (Poland); Col. J. Agostinho (Portugal) ; Dr. A. Gavelin (Sweden).

1. Elections.

   Sir J. S. Flett proposed Prof. Michel-Lévy (France) as President for 1936-1939. Prof. Michel-Lévy asked for any other nominations, and Dr. S. W. Visser proposed the name of Dr. B. G. Escher (Holland). On a vote being taken, Prof. Michel-Lévy was elected by 9 votes to 1.

   Prof. Michel-Lévy then proposed as Vice-Presidents Dr. T. A. Jaggar or Mr. F. A. Perret (United States), Dr. J. E. Richey (Great Britain), and Dr. B. G. Escher (Holland). No other nominations being made, a vote was taken to decide on the U. S. A. Vice-President. Dr. T. A. Jaggar was elected by 6 votes to 5. The other Vice-Presidents were unanimously elected.

   Prof. F. Signore (Italy) was proposed as General Secretary by Prof. Michel-Lévy, and was unanimously elected.

   It was agreed that the nomination of an Assistant-Secretary be left to the discretion of the President.

2. Report of Finance Commission.

   Col. Agostinho read the report of the Finance Commission (consisting of himself and Dr. Axel Gavelin) on the Financial Statement and the Accounts for 1933-1936, which had been submitted by Prof. F. Signore, for the Secretary Prof. A. Malladra. The report was accepted.

10.30 Mr. A. G. MacGregor (Great Britain) gave a short address entitled « Scottish Carboniferous and Permian Volcanoes » illustrated by lantern slides.

Prof. Michel-Lévy thanked the lecturer, and remar-

ked on the very modern of the volcanic products of these ancient volcanoes.

10.50 Mr. S. I. Tomkeieff. (Great Britain) read a paper entitled « A chemical study of the Scottish Carboniferous - Permian Volcanic Province », illustrated by graphs (lantern slides).

Prof. Michel-Lévy thanked the lecturer.

The Assembly adjourned at 11.15.

11.30 Mr. D. Balsillie conducted the Association to the Geological Gallery of the Royal Scottish Museum, where Geological Models of the Edinburgh District, Arthur's Seat (a Carboniferous volcano), Ardnamurchan (a Scottish Tertiary volcanic centre showing ring-dykes and cone-sheets), and Etna were examined, as well as rocks and minerals. Explanations of the Models vere given by Mr. A. G. MacGregor and Dr. J. E. Richey.

Present :

Prof. Michel-Lévy, Col. J. Agostinho, Mr. S. I. Tomkeieff, Sir J. S. Flett, and others.

14.15 At this hour a large party of delegates to the Volcanological and other Associations met at the Holyrood entrance to the King's Park, and were conducted over the well-preserved Carboniferous Volcano of Arthur's Seat by Mr. A. G. MacGregor. Lavas, tuffs. vent-agglomerates and intrusions were examined, and the eruptive history of the volcano was demonstrated. The excursion ended at about 17.30.

Note Regarding the Elections of September 21 st. 1936.

Prof. Michel-Lévy was anxious for Dr. A. L. Day to allow his name to be put forward as the next President, or as the first Vice-President, as the next meeting of the Union was to be in America. Dr. Day was approached by

Sir J. S. Flett, but said that owing to a voyage to New Zealand and prolonged absence from the United States, he did not see his way to accept either position. Since, in view of the fact that the next Assembly was to be in Washington, American names were wanted to be put forward for election as Vice-President, he suggested Dr. T. A. Jaggar and Mr. F. A. Perret as equally suitable.

Prof. Michel-Lévy asked Sir J. S. Flett to allow his name to be considered as a second Vice-President. Sir John, hovever, preferred to suggest the name of Dr. J. E. Richey, who had done much work on the old Tertiary volcanic centres of Scotland and Ireland.

In view of the important work being carried out on active volcanoes by Holland, the senior delegate of that country was approached and asked to suggest a name to be put forward as President or Vice-President. The name of Dr. B. G. Escher was proposed by Dr. Visser, who attended the Second General Assembly of the Association as representative of Holland.

Tuesday, September 22 nd.

The Association met in the Lecture Room, Geography Department, at 10.0, Prof. Michel-Lévy Presiding. Acting Secretaries Dr. J. E. Richey and Mr. A. G. MacGregor were present.

10.00 Dr. W. Q. Kennedy (Great Britain) read his part of a joint paper with Dr. E. M. Anderson on « Crustal Layers and the Origin of Magmas ». Dr. Kennedy discussed the geological and petrological aspects of the topic under review. Graphs and tables were shown as lantern slides.

Prof. Michel-Lévy thanked Dr. Kennedy for his paper, and said that he was bringing new ideas to bear on old problems. These new ideas would arouse interest in France where scientists would test their applicability to areas which showed the recurrent activity

of alkaline and calc-alkaline magmas. In answer to a question by Prof. MICHEL-LÉVY, Dr. KENNEDY said that their theory was based mainly on the evidence provided by Tertiary volcanic districts.

10.40 Dr. E. M. ANDERSON (Great Britain) proceeded to read his part of the joint paper, which dealt with geophysical, geochemical and seismological aspects of the problem. The lecture was illustrated by graphs and diagrams (lantern slides).

11.40 Prof. MICHEL-LÉVY thanked Dr. ANDERSON for his contribution.

Mr. S. I. TOMKEIEFF (Great Britain) in discussing the joint paper expressed his appreciation, but at the same time doubted if the hypothesis was rigidly applicable to different igneous provinces. For instance, the oversaturated basalt magma of the British Tertiary Province was not the same as that of the British Carboniferous-Permian Province. It was richer in alkalis than the undersaturated magma of the same (Tertiary) province, and so indicated a different genetic relationship to that shown by the Carboniferous quartz-dolerite and olivine-basalt magmas. Besides crystallization-differentiation as shown by Dr. KENNEDY's series, one should consider the possibilities of alkali-volatiles diffusion. He thought that the mode of origin of the postulated crustal layers should be discussed.

Sir J. S. FLETT (Great Britain) thanked the authors for their paper as a welcome contribution to the larger problems of petrogenesis. He hoped that when the full text was published the authors would be found to have explained not only the association of tholeiitic and olivine-basalt magmas in the marked contrast between the Scottish Lower Old Red Sandstone (calc-alkaline or andesitic) and Carboniferous (sodic-alkaline) magmas.

Dr. G. W. TYRRELL (Great Britain) agreed with much that Dr. KENNEDY had said and welcomed his redefinition of the terms plutonic and volcanic.

12.00 Dr. G. W. Tyrrell (Great Britain) delivered his paper « Fissure Eruptions and Flood Basalts » which was illustrated by maps and photographs from many parts of the world.

Prof. Michel-Lévy thanked Dr. Tyrrell for his interesting lecture.

Mr. S. I. Tomkeieff (Great Britain) said that he thought the evidence of the occurrence of dykes and sills in connection with the Clyde Carboniferous lava-plateau and also with the Antrim Tertiary lava-plateau suggested similar modes of origin as products of multiple-vent of shield volcanoes.

Dr. Tyrrell upholding his interpretation of the lavas of the Antrim plateau as flood-basalts produced by fissure-eruptions pointed out that the Antrim basalts had probably a wide extent under the sea to the north, and that they were associated with a dyke-swarm. The Clyde Plateau on the other hand was of limited extent, was associated with far more numerous volcanic necks, and had no extensive dyke-swarm.

The Meeting adjourned at about 12. 45.

14.30 Dr. G. W. Tyrrell (Great Britain), using Mr. Kidd's Model, gave an outline of the geology and geological history of the Island of Arran (in the west of Scotland), with its Tertiary granites and ring-complex with explosion-breccias.

Mr. J. Kidd (Geological Survey of Scotland) briefly explained the various stages in the making of the Model.

Prof. Michel-Lévy thanked Messrs. Tyrrell and Kidd for their demonstration.

The Meeting adjourned about 15.30.

The following were present during the morning: Dr. L. Hawkes, Sir J. S. Flett, Mr. S. I. Tomkeieff, Mr. D. Balsillie. In the afternoon Mr. S. I. Tomkeieff, Dr. A. L. Day and others.

Wednesday, September 23rd.

The Association met in the lecture room, Geography Department, at 10.15, Prof. Michel-Lévy presiding. Acting Secretaries Dr. J. E. Richey and Mr. A. G. MacGregor were present.

10.15 Dr. J. E. Richey (Great Britain) delivered a lecture on the Tertiary volcano of Mull, Scotland, illustrated by lantern slides and diagrams.

11.00 Dr. E. M. Anderson (Great Britain) gave a brief address entitled « Cone - sheets and Ring - dykes - the Dynamical Explanation ».

11.23 Prof. Michel-Lévy thanked the authors for their paper and commented on the volcanological interest of the structures found in the Scottish Tertiary Volcanoes and of the theories relating to volcanic magma-reservoirs that had been based on them.

Mr. Tomkeieff asked Dr. Anderson to consider the physico - chemical conditions of the cooling magma and the possible influence of volatiles accumulating during consolidation in the upper part of the magma chamber. He thought that cone - sheet fractures might be due to explosion.

11.27 Colonel J. Agostinho (Portugal) gave an address entitled « Volcanological Work in the Azores, 1933-36 ». Prof. Michel-Lévy thanked the author. Mr. A. G. MacGregor asked some questions on the scope of volcanological and seismological work in the Azores and the personnel that carried it on.

11.45 The Meeting was adjourned.

14.15. Mr. A. G. MacGregor led a second excursion to Arthur's Seat. which was attended by a number of delegates, mainly from other Associations, who had been unable to attend the first excursion on Monday 21st.

The excursion ended at 17.30.

Thursday, September 24th.

Third General Assembly of the Association of Volcanology.

The Assembly was held in the Lecture Room, Geography Department, at 10.00, Prof. A. Michel-Lévy (Acting President) presiding. The Acting Secretaries, Dr. J. E. Richey and Mr. A. G. MacGregor, were present. Also present, Col. J. Agostinho, Dr. A. Imamura and Dr. A. Gavelin.

10.00 Prof. Michel-Lévy read (1) the report of the Finance Commission (Dr. A. Gavelin and Col. J. Agostinho) on the accounts of the Bureau as presented by Prof. Signore, (2) the Acting President's report on the work done and publications presented during the Edinburgh Assembly, (3) resolutions to be sent forward to the Union for adoption.

The reports and resolutions were approved.

Prof. Michel-Lévy then read (1) a cablegram from Prof. Machado e Costa (Portugal) regretting inability to attend the Edinburgh Assembly and sending good wishes, (2) a letter and report received from Dr. A. Imamura, President of the Commission pour l'Étude des Raz de Marée.

10.20 Dr. A. Imamura said a few words on Prof. A. Tanakadate's paper on « Volcanic Activity in Japan during the period between July 1934 and October 1935 »; and then gave an outline of Prof. Tanakadate's most recent work, in the Urakas volcanic islands at the southern extremity of the Huzi Zone. Five of some nine islands are active. Urakas is at present likely to be in a Strombolian phase, and the northern peak of Pagan Island has a crater resembling that of Vesuvius.

10.30 Dr. J. E. Richey summarised Prof. Tanakadate's paper dealing with the period 1934 - 1935, which Dr. Imamura had referred to, and copies of which had been presented to the Association for distribution.

Prof. Michel-Lévy thanked Dr. Richey for his summary.

11.00 Mr. A. G. MacGregor read Sir J. S. Flett's report on « British Volcanological Research, 1933-1936 ». Prof. Michel-Lévy thanked Mr. MacGregor for reading the report, and moved a vote of thanks to the Local Secretaries during the Edinburgh Assembly.

11.10 Col. J. Agostinho moved a vote of thanks to Prof. Michel-Lévy for the energy and ability he had shown as Acting President during the Edinburgh Assembly. The proceedings terminated at 11.15.

14.30 Prof. Michel-Lévy accompanied by Dr. J. E. Richey and Mr. A. G. MacGregor represented the Association of Volcanology at a General Assembly of the Union, held in the Music Classroom of the University. Prof. Michel-Lévy read his report on the work of the Association during the Edinburgh Assembly and the resolutions put forward by the Association. These were approved by the General Assembly of the Union.

Friday, September 25th.

Prof. A. Michel-Lévy (Acting President) and Dr. J. E. Richey and Mr. A. G. MacGregor (Acting Secretaries) represented the Association of Volcanology at the Executive Committee and Final Administrative Meetings of the Union, held in the Geodesy lecture - room, Geography Department, at 10.30 and 14.00.

Allocution du Prof. Michel-Lévy à l'ouverture de la première séance de l'Assemblée générale de l'Association internationale de Volcanologie, le 17 Septembre 1936

Messieurs,

Dans sa dernière Assemblée générale, tenue a Lisbonne, en 1933, l'Association internationale de Volcanologie avait désigné le Prof. Kténas comme Président et le Prof. Malladra comme Secrétaire général.

Nous avons eu le grand regret de perdre M. le Professeur Kténas en 1935. Une notice nécrologique lui a été consacrée dans le dernier Bulletin de l'Association. J'ajouterai à cette notice quelques souvenirs personnels ; M. Kténas était venu à maintes reprises à Paris où il a longuement fréquenté le laboratoire de Minéralogie du Muséum d'Histoire naturelle, profitant largement des enseignements de M. le Prof. Lacroix. C'était un pétrographe très averti et un savant très ardent qui laisse malheureusement inachevée une importante contribution à l'étude des laves tertiaires et quaternaires de la Mer Egée. Sa disparition prématurée que nous avons cruellement ressentie vous explique pourquoi j'occupe aujourd'hui le fauteuil présidentiel, comme vice président et seul représentant de votre bureau.

Notre Secrétaire Général, le Prof. Malladra, n'a, en effet, pu se rendre parmi nous, non plus que notre Secrétaire adjoint le Professeur Signore ; je vous donnerai tout à l'heure connaissance de la lettre qu'il m'a remise.

Mon rôle s'annonce ainsi assez ingrat et je fais appel dès l'abord à toute votre indulgence.

Je dépose de la part du Prof. Signore les comptes du Bureau Central de Volcanologie, un exemplaire du Bulletin année 8 ème, et des lettres relatives à l'assemblée de l'Association, parvenues à Naples.

Je me fais votre interprète pour exprimer à nos hôtes écossais notre grand plaisir d'être reçus dans cette belle

et célebre cité d'Edimbourg, au milieu d'une région particulièrement intéressante pour l'histoire ancienne du volcanisme ; je remercie de leur très aimable accueil Sir J. Flett et ses collaborateurs qui se sont dévoués sans compter, à la réussite de notre Assemblée et je vous demande la permission de rappeler en terminant la mémoire d'un éminent géologue de la génération précédente qui a illustré la géologie et la volcanologie écossaise, je veux parler de Sir. Arc. Geikie, que j'ai eu l'honneur de connaitre alors qu'en 1900 il venait visiter les volcans éteints de la chaîne des Puys et du Mt. Dore.

J'exprime le voeu que nos séances soient fécondes pour la volcanologie et pour l'avenir de notre Association.

Rapport sur le fonctionnement du Bureau dans le triennat 1933-36

Le Secrétaire général, Prof. A. MALLADRA, m'a chargé d'étendre le rapport des travaux du Bureau C. I. de Volcanologie dans le triennat 1933-36. La charge honorable a été pour moi extrèmement agréable, ayant vécu avec le Prof. MALLADRA en comunion de travail pour un espace de dix ans environ.

Le Bureau C. I. de Volcanologie à la suite des élections à Lisbonne résulta ainsi constitué : Président. Prof. C. A. KTÉNAS ; Vice-présidents, proff. A. MICHEL-LÉVY, A. A. OLIVEIRA MACHADO e COSTA, H. TANAKADATE ; Secrétaire général, prof. A. MALLADRA ; Secrétaire adjoint, Prof. F. SIGNORE

Le 24 janvier 1935 notre Association perdait son Président, le Prof. C. A. KTÉNAS. Quelques mois auparavant alle avait été privée d'un autre de ses membres éminents : le docteur HENRY STEPHENS WASHINGTON, qui avait été Vice-président jusqu'aux élections de Lisbonne.

La considération de la quelle jouissaient nos défunts dans le monde scientifique et parmi les membres de l'Union même fut demontrée par les nombreuses attestations de chagrin parvenues au Bureau de Volcanologie.

Dans le Bulletin qui vient de paraître et qui se trouve en distribution, les deux illustres disparus sont dignement commémorés.

Dans le triennat écoulé le Bureau a continué à fonctionner dans l'Observatoire du Vésuve, où sont placés la Bibliothèque et les Archives, et il a expliqué regulièrement les tâches qui lui avaient été confiées par les différentes assemblées.

La Bibliothèque est riche en publications périodiques, oeuvres de volcanologie et brochures, offertes en échange du Bulletin ou en hommage. Leur nombre augmente tous les jours.

Je saisis l'occasion pour remercier les différentes nations qui envoient leurs publications et particulièrement l'Engleterre, le Japon, les État-Unis d'Amérique et la France.

L'Académie de France a fait hommage à notre bibliothèque de la collection des Comptes Rendus depuis le 1930.

Les principales Académies et Associations scientifiques italiennes ont elles aussi concouru avec un grand élan à la formation de notre bibliothèque en envoyant des oeuvres.

Dans le triennat le secrétariat se maintint en correspondance avec les différentes Académies, les Conseils nationaux des recherches, les associations de l'Union même et avec leurs membres, et il a tâché de plus de faciliter la visite du Vésuve et des Champs Phlégréens aux savants des différents pays, qui s'étaient adressés à lui. Et beau. coup de fois il s'occupa même de leur accompagnement.

Dans ce triennat ont été publiées deux années du Bulletin, comprenant chacune quatre numéros. L'année septième (n. 23-26) contenant une partie des notes et mémoires, présentés à la réunion de Lisbonne, a été distribuée dans le 1934. L'année huitième (n. 27-30) complète la publication des notes, rapports et mémoires susdit et en reporte des nouveaux. Cette dernière est en distribution.

On n'a pu publier des autres numéros faute de matériel.

J'adresse une chaude prière aux membres de l'Association, pour qu'ils veuillent envoyer des mémoires pour la publication, puisque sans l'intérêt de tous il est impossible que le Bulletin puisse paraître par intervalles plus courts, En ordonnant les différentes nations selon le nombre croissant des travaux envoyés du commencement de la publication, 1924, jusqu'à présent, nous avons : Cile 1, Tchéco-Slovaquie 1, San Salvador 1, Suisse 2, Grande-Brétagne 2, Portugal 4, Suède 4, Hollande 5, Etats-Unis d'Amérique 5, Japon 6, Espagne 8, Grèce 9, France 24, Italie 55.

Je dois signaler avec regret le peu d'intérêt expliqué par les ministres de la Marine des Nations faisant partie de l'Union dans l'envoi des nouvelles sur les éruptions sous — marines relevées par les registres de bord. Il est désirable que toutes les nations, come déjà l'Angleterre,

comprennent l'importance pratique et scientifique que telles nouvelles ont pour le progrès de la volcanologie. — Il serait encore désirable que les instituts intéressés à l'étude des volcans fassent parvenir à propos au Bureau C. I. de V. des rapports sommaires sur les éruptions et sur les phénomènes nouveaux qui se manifestent dans les volcans actifs pour pouvoir en donner tout de suite avis dans le Bulletin.

J'eus déjà l'opportunité d'exposer au Conseil international des Unions scientifiques, qui se réunit à Bruxelles en juillet 1934, l'activité expliquée par l'Association, et pour elle par le Secrétariat, depuis son institution jusqu'à présent. La rélation présentée par moi est reportée dans la huitième année du Bulletin.

Parmi les différentes tâches assignées au Bureau I., il y a celle de récueillir et préparer le materiel pour la publication d'une bibliographie volcanologique mondiale et d'un catalogue des volcans actifs, quiescents ou récemment éteints, qui réponde à des règles générales, déjà exposées par moi dans la rélation susmentionnée. De ces deux travaux vraiment grandioses ont été déjà récueillies beaucoup de données et chaque année, avec les économies réalisées par le secrétariat, on met de côté les fonds nécessaires pour faire face à la dépense pas légère de la publication.

Enfin par suite de l'intérêt expliqué par le secrétariat du Bureau C. I. et avec les moyens financiers accordés par le secrétariat même, par l'Observatoire du Vésuve, par le Comité italien pour la Géodésie et la Géophysique et par la Commission géodésique italienne ont été effectuées sous la direction du Sen. Prof. Soler deux campagnes gravimetriques au pied du Vésuve et dans les Champs Phlégréens. Les importants résultats de ces recherches paraîtront d'une manière detaillée dans le prochain volume de notre Bulletin.

Avec ces recherches on a enfin réalisé le projet présenté par feu le Prof. Kövesligethy, à la première réunion de la Commission permanente de l'Association internationale de séismologie qui se réunit à Rome en octobre 1906.

Prof. Francesco Signore
Secrétaire adjoint de l'Association de Volcanologie

UNION GÉODÉSIQUE ET GÉO

BUREAU CENTRAL INTERNA

Résumé des comptes de l'Association de

Assemblée générale d'Edimbourgh

ENTRÉE

DATE	DESCRIPTION	SOMME		CHANGE		L. Ital.	
Sept. 1933	Existence de caisse . .					135197	77
Janvier 1935	Reçu du Secrétaire Général de l' Union Fr. S.	12254	00	374	½	46473	25
Mai »	Reçu du Secrétaire Général de l' Union Fr. S.	3000	00	391	½	11745	00
Juillet »	Reçu du Secrétaire Général de l' Union Fr. S.	5949	00	397	½	23647	05
Décemb. »	Reçu du Secrétaire Général de l' Union £ Ster.	295	00	61	90	18230	00
	Intérêts sur le dépôts					1175	00
					Total de l'entrée	236468	07

PHYSIQUE INTERNATIONALE

TIONAL DE VOLCANOLOGIE

volcanologie pour les années 1933 - 1936.

17-24 Septembre 1936.

SORTIE

Titre	DESCRIPTION	Annexé	L. Ital.	
1	Bullet. Volcanol. impress., clichès, traductions, etc.		15688	00
2	Contributions accordées par le Bureau . .		10000	00
3	Transports, voyages, pourboires etc. . .		4015	00
4	Bureau : dépenses		12773	00
	Total de la sortie		42477	00
	Actif au 10 Sept. 1936, provisionné pour la publication de la Bibliographie volcanologique et pour autres travaux sous presse		193991	07
	Total L. ital.		236468	07

S. E. O.

Napoli, 10 Septembre 1936

Le Secrétaire adjoint

FRANCESCO SIGNORE

Rapport de la Commission de Finance

ASSOCIATION DE VOLCANOLOGIE

Les soussignés chargés par l'Association d'examiner les comptes presentés par le Bureau de l'Association, à Naples, pour les années 1933-1936, se terminant le 10 Septembre 1936, ont reconnu que ces comptes étaient exacts que les documents joints étaient au complet, et qu'un actif est accusé du montant de cent quatrevingt treize mille, neuf cent quatrevingt onze lires italiennes, et sept centimes, (193.991,07) que le secrétaire déclare être provisionné pour la publication de la Bibliographie Volcanologique et pour autres travaux sous presse.

Edimbourgh, le 21 Septembre 1936.

Axel Gavelin
J. Agostinho

GEOLOGICAL SURVEY OFFICE,
19, Grange Terrace,
EDINBURGH, 9.
SCOTLAND.

September, 25th, 1936.

To the Chairman,
National Committee of
International Union of Geodesy and Geophysics.

Dear Sir,

Would you kindly forward the enclosed circular letter to the Chairman of your National Sub-Committee for Volcanology, or, if this Sub-Committee is not constituted, to a Delegate whom you may consider suitable.

Yours faithfully,

J. E. Richey
for Joint Acting Secretaries for the Volcanological
Association for the Edinburgh Assembly.

Volcanological Association, International Union of Geodesy and Geophysics, Edinburgh Assembly, September 17th to 26th.

The University,
EDINBURGH.

September 25th, 1936.

To the Chairman of the Volcanological Sub-Committee of the International
National Comittee of
Union of Geodesy and Geophysics.

Dear Sir.

We are instructed to write to you in regard to the following matters, in which your co-operation is more especially desired at the present time.

I. Reports of Volcanic Action and Volcanological Research from Countries adhering to the Union.

a) At the Edinburgh Assembly, which is now practically concluded, reports covering the period of three years, 1933-1936, have been received from four countries only, namely, Great Britain, Portugal, Sweden, and Japan.

It is very desirable that reports should be made regularly, for publication in the Bulletin Volcanologique, the official organ of the Association.

Would you be so good as to co-operate in this matter as soon as possible, so that a complete series of reports for the period 1933-1936 may be published.

b) These reports, submitted by National Volcanological Sub-Committees, should be as concise as possible. They should include a bibliography of all important papers published during the period under review (1933-1936), and also resumés of the more outstanding works.

II. Encouragement of Volcanological Research.

a) Grants of Money in Aid of Research.

The Bureau of the Association wishes to promote volcanological research by providing some financial aid in cases where assistance may be of special advantage to our Science.

The Bureau will therefore be glad to consider applications from your National Sub-Committee for financial Assistance for useful schemes of research, in countries where active volcanoes occur.

As the funds at the disposal of the Bureau for the encouragement of research are strictly limited at the present time, the work for which financial assistance is requested should be of importance to volcanologists generally, and should not be such as would naturally form a part of any National routine scheme of observations.

b) Publication.

The Bureau thinks that the Bulletin Volcanologique should include the results of volcanological research, from all parts of the world, which may be of general interest. The Bureau will therefore be glad to consider for publication any contributions which your National Sub-Committee may see fit to submit. The Bulletin is published twice yearly as a rule.

III. For your information, a copy of the Acting President's Report to the Edinburgh Assembly is enclosed.

IV. Any correspondence in connection with the above matters should be addressed to the President of the Association :

Prof. A. Michel-Lévy,
26, rue Spontini,
PARIS, France.

Yours faithfully,
J. E. Richey
For Joint Acting Secretaries for the Volcanological Association for the Edinburgh Assembly.

Report of the International Association of Volcanology, on the work of the General Assembly at Edinburgh, September 1936

The countries which took an active part in the work of the Assembly were : United States of America, France, Great Britain, Japan, Portugal, Sweden.

I. — Administration Questions.

a) Owing to the death of the President (Prof. KTÉNAS) the first Vice-President (Prof. A. MICHEL-LÉVY) presided at the Assemblies. Dr. J. E. RICHEY and Mr. A. G. MAC GREGOR (the local secretaries) were appointed joint temporary secretaries for the Association in the absence of Prof. MALLADRA and Prof. SIGNORE.

b) Approval of the accounts of the Bureau at Naples :

The Assembly approved the report of the Finance Commission, a copy of which is attached.

c) Estimated Budget :

Whatever sum is placed at the disposal of the Bureau will be used, *1st.* for the payment of the sums outstanding which are due to the Commission on Tidal Waves and of the sums which will be paid to it in the future. *2nd.* for the expense of printing the Bulletin International Volcanologique. For this approximately two thirds of the balance will be used. *3rd.* for financial allocations to scientists or scientific organisations belonging to countries in which active volcanoes occur, for specific research work. For this the remaining one third of the balance will be used.

d) Election of Bureau for the years 1936 - 1939.

The following were elected. President : Professor A. MICHEL-LÉVY (France). Vice Presidents : Dr. T. JAGGAR (United States), Dr. J. E. RICHEY (Great Britain), Prof.

Dr. B. G. Escher (Holland). General Secretary: Professor F. Signore (Italy).

The designation of the Assistant Secretary was left to the President.

II. — Scientific Questions.

a) Presentation of Publications.

The following works were presented:

Deux volumes du Bulletin de l' Association de Volcanologie n.º 7 et 8.

Transactions of the American Geohysical Union. Parts I and II.

A. Lacroix, « Le Vulcan Actif de l' Ile de la Réunion et ses Products », Paris, 1936.

H. Tanakadate, « Volcanic Activity in Japan during the Period between July 1934 and October 1935 ». Japanese Journal of Astronomy aud Geophysics, vol. XIII, n. 2, 1936.

A. Michel-Lévy, et H. Muraour, Ten offprints on the luminous phenomena resulting from the detonation of explosives.

M. MacGregor and A. G. MacGregor, « The Midland Valley of Scotland », Memoir Geological Survey, Gt. Britain, 1936.

J. E. Richey, « The Tertiary Volcanic Districts of Scotland », Memoir Geological Survey, Gt. Britain, 1936.

Bulletin géodésique, organe de l' Association de Géodésie, 1936.

Rapport sur l'activité de l' Observatoire Sismologique de Budapest, pendant les années 1933 à 1935, 1936.

Seismological Observations in Japan, published by the Central Meteorological Observatory, Tokyo, 1936.

b) Scientific Communications: see attached list.

c) Resolutions to be submitted for the approval of the Union.

1. — The Association recalls the importance there is, both from the scientific and practical points of view, in getting the marine authorities of the countries belonging

to the Union to send to the International Bureau of Volcanology news of submarine eruptions noted in ships logs. Only Great Britain has up to the present done this.

2. — The Assembly asks that in countries which have active volcanoes there should be undertaken (a) gravimetric surveys around these volcanoes, to be repeated after certain time-intervals, and (b) research on the intensity and nature of the luminous phenomena which accompany certain volcanic explosions, carried out by photography and spectroscopy.

A. Michel-Lévy

Association of Volcanology. Edinburgh Meeting. Sept. 1936 : Scientific Communications, etc.

Saturday, 19th. Morning.

1. — Summary Report of the Researches in Sweden on Volcanic and related Phenomena during the period 1933-1936. By Dr. A. Gavelin (Sweden).
2. — Le Volcan Actif de l'Ile de Réunion. By Prof. A. Lacroix (France). (Communicated).
3. — Détonation des explosifs et Explosions volcaniques. By Prof. A. Michel-Lévy (France).

Monday, 21st. Morning.

1. — Scottish Carboniferous and Permian Volcanoes. By A. G. MacGregor (Great Britain).
2. — Chemical Study of Scottish Carboniferous - Permian Volcanic Province. By S. I. Tomkeieff (Great Britain).
3. — Visit to Geological Gallery, Royal Scottish Museum, to see models of the eroded volcanoes of Arthur's Seat and Ardnamurchan (demonstrated by A. G. MacGregor and J. E. Richey).

Afternoon.

Excursion to the volcano of Arthur's Seat, Edinburgh. Leader, A. G. MacGregor.

Tuesday, 22nd. Morning.

1. — Crustal Layers and the Origin of Magmas. By W. Q. Kennedy and E. M. Anderson (Great Britain).
2. — Fissure Eruptions and Flood Basalts. By G. W. Tyrrell (Great Britain).

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Afternoon.

1. — Exhibition of model of the Island of Arran. Scotland, showing Tertiary igneous rocks, etc. Method of making the model demonstrated by J. Kidd (Great Britain).
2. — Summary Account of the Geology of Arran. By G W. Tyrrell (Great Britain).

Wednesday, 23rd. Morning.

1. — The Tertiary Volcano of Mull, Scotland. By J. E. Richey (Great Britain).
2. — Cone-sheets and Ring-dykes -- the Dynamical Explanation. By E. M. Anderson (Great Britain).
3. — Volcanological Work in the Azores, 1933-1936. By Colonel J. Agostinho (Portugal).

Afternoon.

Second Excursion to Arthur's Seat volcano. Leader A. G. MacGregor.

Thursday, 24th. Morning.

1. — Volcanic Activity in Japan between July 1934 and October 1935. By H. Tanakadate (Japan). (Communicated).
2. — Report on British Volcanological Research, 1933-36. By Sir John Flett (Great Britain).

UNION GÉODÉSIQUE ET GÉOPHYSIQUE INTERNATIONALE

SECRÉTARIAT
de la Commission
pour l'étude
DES RAZ DE MARÉE

S. Rue Raynouard - Paris (16)

Edinburgh, le 22 Septembre 1936

Monsieur le Président,

J'ai l'honneur de vous adresser ci-joint copie du procès-verbal de la réunion tenue par la Commission pour l'Etude des raz de marée le 22 septembre 1936 à Edinburgh.

Je me permets d'attirer votre attention sur les dispositions que la Commission a proposé de soumettre à l'agrément des quatre Associations sous le patronage desquelles elle est placée.

Si ces dispositions reçoivent l'agrément de l'Association que vous présidez, je vous serais reconnaissant de vouloir bien m'en faire part, et, éventuellement, de porter à la connaissance de bureau de l'Union les questions susceptibles de l'intéresser, par exemple celles relatives au budget annuel et à l'utilisation des crédits.

Je vous prie d'agréer, Monsieur le Président, l'expression de ma considération la plus distinguée.

A. IMAMURA
Président de la Commission
pour l'Etude des raz de marée

Procès-Verbal de la Réunion de la Commission pour l'étude des raz de marée (Edinburgh, 22 Septembre 1936)

La Commission pour l'étude des raz de marée s'est réunie à Edinburgh, le 22 Septembre 1936, à 10 heures, dans les locaux de l'Université, sous la présidence de M. Imamura, Président.

Après avoir souhaité la bienvenue aux membres présents, le président donne la parole au Secrétaire.

Celui-ci fait connaître qu'un rapport sur l'activité de la Commission pendant l'année 1936 sera inséré dans le prochain numéro des Annales de la Commission. Il donne lecture d'un rapport concernant les travaux de la Commission depuis le Congrès de Lisbonne.

Ce rapport comporte les chapitres suivants :

Organisation de la Commission :

Objet de la Commission ;

Situation financière ;

Réalisation des décisions prises dans le Congrès antérieur ;

Sujets à soumettre aux Délibérations de la Commission à Edimbourg.

Sur la proposition du Président, ce rapport est approuvé par la Commission.

La Commission passe ensuite à l'examen des sujets présentés par le Secrétaire.

Elle adopte les dispositions ci-après, qu'elle se propose de soumettre à l'agrément des quatre Associations dont elle relève.

1. — Maintien jusqu'à la fin du prochain Congrès de l'Union, du budget annuel de 8500 francs français, voté par les Assemblées de Stockolm et de Lisbonne. Cette somme étant payés, par quarts, par les quatres Associations de Séismologie, Météorologie, Océanographie et Volcanologie ;

2. — Continuation de la publication, sous la forme actuelle, des Annales de la Commission des raz de marée ;

3. — Utilisation des crédits de la Commission laissés disponibles par la publication des Annales à la réalisation de recherches (emploi de dispositifs pour l'enregistrement de la houle et des envahissements brusques du littoral par la mer, films, études sur modèles réduits, etc.) ;

4. — Extension dans tous les pays intéressés, des recherches relatives aux envahissements brusques du littoral par la mer ;

5. — Organisation, sur un plan plus général, de l'étude des envahissements brusques du littoral par la mer. La première mesure préconisée est la liaison avec l'Organisation Météorologique Internationale (Sous - Commission de la Houle) en vue de l'introduction systématique dans les messages météorologiques de renseignement aussi précis que possible sur l'état de la mer (amplitude, période, vitesse, direction de la houle, etc.). La communication à la Commission de la documentation ainsi recueillie pourrait ensuite être exploitée pour des fins spéculatives ;

6. — Mise au point d'une terminologie se rapportant aux différents types d'envahissements du littoral par la mer ;

7. — Désignation de MM. Charvet et Roux comme membres de la Commission.

La Commission, après avoir reçu les démissions réglementaires du Bureau sortant, décide de le réélire pour une période qui prendra fin à l'issue du prochain Congrès de l'Union. L'ordre du jour étant épuisé, la séance est levée à 10 heures 5.

Approuvé :
le Président de la Commission
A. Imamura

Le Secrétaire de la Commission,
H. Hubert

UNION GÉODÉSIQUE ET GÉOPHYSIQUE INTERNATIONALE

ASSOCIATION DE VOLCANOLOGIE

Roma, 15 Novembre 1936 - XV.

I proff. MALLADRA Grand Uff. ALESSANDRO, Segretario Generale uscente e FRANCESCO SIGNORE, Segretario Generale entrante dell'Associazione di Vulcanologia dell' Unione geodetica e geofisica internazionale, si sono incontrati in Via Flaminia, 389, residenza del MALLADRA, il giorno 15 novembre 1936 - XV, alle ore 11, per la consegna della Cassa della suddetta Associazione di Vulcanologia, il cui ammontare è di Lire italiane Centonovantatremilanovecentonovantuno e $^{7}/_{100}$ — dico L. 193.991,07, come risulta dal rendiconto 1933-36 dell'Associazione di Vulcanologia presentato e approvato dall'Assemblea Generale dell'Unione geodetica e geofisica, tenutasi ad Edimburgo dal 17 al 26 Settembre 1936, e da apposita ricevuta.

Prof. ALESSANDRO MALLADRA
Prof. FRANCESCO SIGNORE

Lettre aux Présidents des sous-comités nationaux de Volcanogie

UNION GÉODÉSIQUE ET GÉOPHYSIQUE INTERNATIONALE

Bureau Central International de Volcanologie

Pour la Correspondance :
Prof. FRANCESCO SIGNORE
Corso Vittorio Emanuele, 7
Napoli (Italie)

Naples,

Monsieur le Président et cher Collègue,

Le Bureau de l' Association internationale de Volcanologie a décidé d'envoyer dorénavant à chaque pays faisant partie de l' Union, un nombre d' exemplaires du Bulletin volcanologique, organe dell' Association, proportionnel au nombre des parts unitaires de 2000 Frs. suisses, payées par eux, à raison de 4 exemplaires par part.

Le Comité national que vous présidez est prié, en conséquence, de vouloir bien indiquer sans delai au Secrétariat général les organismes scientifiques et les savants de votre pays s'intéressant aux études volcanologiques et les plus qualifiés pour recevoir le Bulletin. Ces organismes scientifiques et savants recevront le Bulletin par priorité dans la limite du nombre d'exemplaires attribué à votre pays.

Le secrétariat est autorisé à envoyer en outre, sur demande, un certain nombre de Bulletins supplémentaires aux pays qui par leurs conditions géologiques ont un plus grand nombre de savants intéressés à la volcanologie.

Vous trouverez ci-joint la liste des organismes scientifiques et des savants qui ont jusqu' ici reçu le Bulletin et le nombre des exemplaires qui sera désormais réservé a votre pays.

Veuillez agréer, Monsieur le Président et cher Collègue, l'assurance de mes sentiments les plus distingués et devoués.

Le Secrétaire général directeur du Bureau
FRANCESCO SIGNORE

SOMMAIRE

Notes, mémoires et rapports de Volcanologie

présentés à l'Assemblée d' Édimbourg - Septembre 1936.

Chronique de l' Union Géodésique et Géophysique internationale

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*(**Pubblicato in luglio 1937**)*